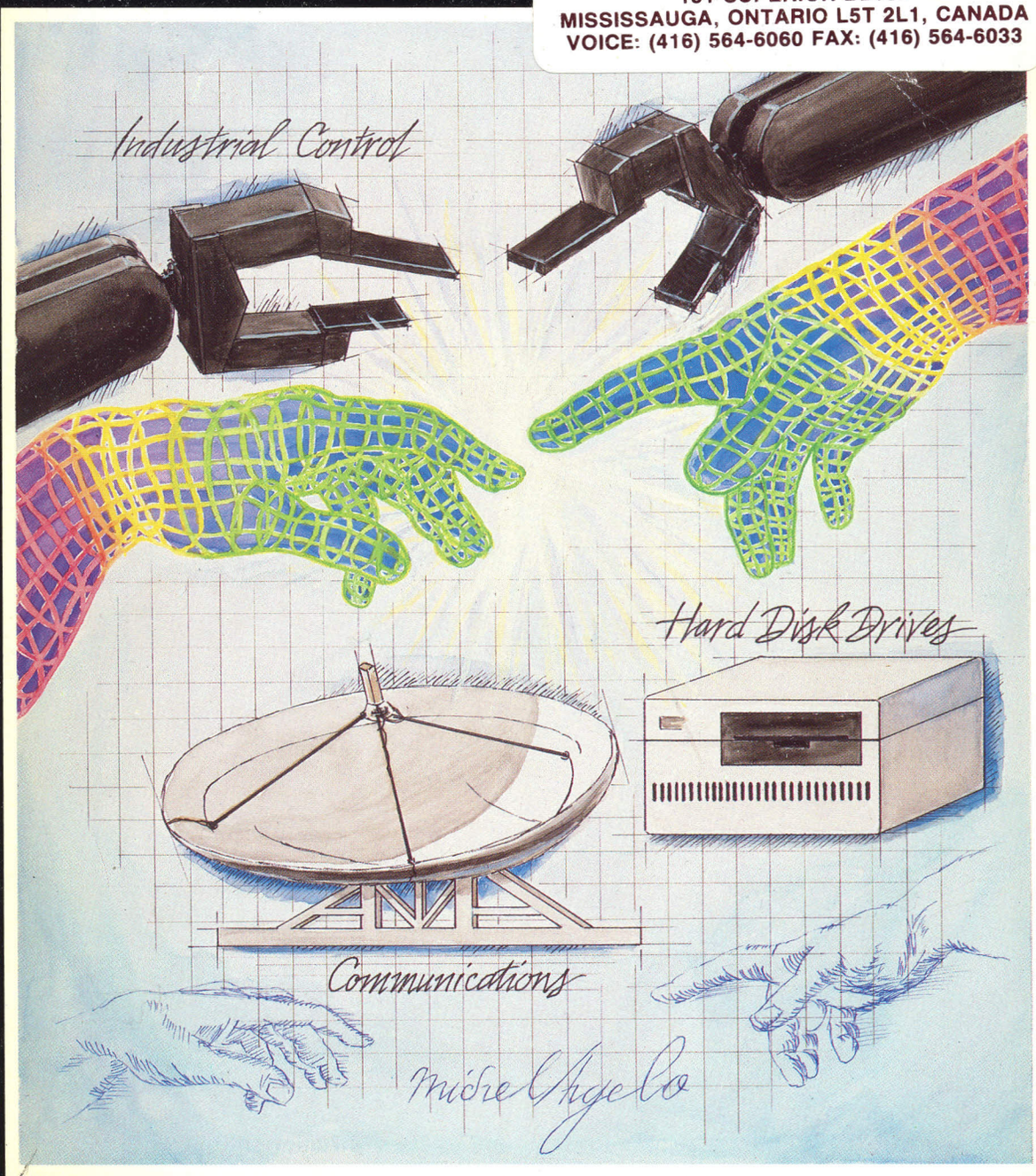
intel®

16-/32-Bit Embedded Processors

HAMILTON/AVNET
151 SUPERIOR BLVD.
MISSISSAUGA, ONTARIO L5T 2L1, CANADA
VOICE: (416) 564-6060 FAX: (416) 564-6033



Benedict Norbert Wong

Order Number: 270647-003

intel®

LITERATURE

To order Intel Literature or obtain literature pricing information in the U.S. and Canada call or write Intel Literature Sales. In Europe and other international locations, please contact your ***local*** sales office or distributor.

INTEL LITERATURE SALES
P.O. BOX 7641
Mt. Prospect, IL 60056-7641

In the U.S. and Canada
call toll free
(800) 548-4725

CURRENT HANDBOOKS

Product line handbooks contain data sheets, application notes, article reprints and other design information. All handbooks can be ordered individually, and most are available in a pre-packaged set in the U.S. and Canada.

TITLE	INTEL ORDER NUMBER	ISBN
SET OF THIRTEEN HANDBOOKS (Available in U.S. and Canada)	**231003**	**N/A**
CONTENTS LISTED BELOW FOR INDIVIDUAL ORDERING:		
COMPONENTS QUALITY/RELIABILITY	210997	1-55512-132-2
EMBEDDED APPLICATIONS	270648	1-55512-123-3
8-BIT EMBEDDED CONTROLLERS	270645	1-55512-121-7
16-BIT EMBEDDED CONTROLLERS	270646	1-55512-120-9
16/32-BIT EMBEDDED PROCESSORS	270647	1-55512-122-5
MEMORY PRODUCTS	210830	1-55512-117-9
MICROCOMMUNICATIONS	231658	1-55512-119-5
MICROCOMPUTER PRODUCTS	280407	1-55512-118-7
MICROPROCESSORS	230843	1-55512-115-2
PACKAGING	240800	1-55512-128-4
PERIPHERAL COMPONENTS	296467	1-55512-127-6
PRODUCT GUIDE (Overview of Intel's complete product lines)	210846	1-55512-116-0
PROGRAMMABLE LOGIC	296083	1-55512-124-1
ADDITIONAL LITERATURE: (Not included in handbook set)		
AUTOMOTIVE HANDBOOK	231792	1-55512-125-x
INTERNATIONAL LITERATURE GUIDE (Available in Europe only)	E00029	N/A
CUSTOMER LITERATURE GUIDE	210620	N/A
MILITARY HANDBOOK (2 volume set)	210461	1-55512-126-8
SYSTEMS QUALITY/RELIABILITY	231762	1-55512-046-6

intel®

16-/32-Bit Embedded Processors

Explore the infinite possibilities of Intel's high performance embedded processors. Whether you are designing in the newest and fastest member of the i960 architecture, the industry standard 186 family or the 386™ microprocessor-based 376™ embedded processor, you will want this comprehensive handbook. These architectures have been designed to meet the needs of embedded applications such as machine control, robotics, process control, avionics and laser printer applications.

This handbook provides programming and hardware system design information. Data sheets cover the 80186/80C186 family, the i960 family, including the i960 KA/KB, the i960 CA, and for the first time, the military version i960 MC. In addition, one entire chapter covers the 376 embedded processor, and another contains extensive information about development support tools.

MISSISSAUGA, ONTARIO
VOICE: (416) 564-6060 FAX: (416) 564-6033

Printed in USA/0191/45K/RRD/DM
Embedded Control

ISBN# 1-55512-122

Intel Corporation is a leading supplier of microcomputer components, modules and systems. When Intel invented the microprocessor in 1971, it created the era of the microcomputer. Today, Intel architectures are considered world standards. Whether used in embedded applications such as automobiles, printers and microwave ovens, or as the CPU in personal computers, client servers or supercomputers, Intel delivers leading-edge technology.

16-/32-BIT EMBEDDED PROCESSOR HANDBOOK

1991

About Our Cover:

Thinkers, inventors, and artists throughout history have breathed life into their ideas by converting them into rough working sketches, models, and products. This series of covers shows a few of these creations, along with the applications and products created by Intel customers.

Intel Corporation makes no warranty for the use of its products and assumes no responsibility for any errors which may appear in this document nor does it make a commitment to update the information contained herein.

Intel retains the right to make changes to these specifications at any time, without notice.

Contact your local sales office to obtain the latest specifications before placing your order.

The following are trademarks of Intel Corporation and may only be used to identify Intel products:

287, 376, 386, 387, 486, 4-SITE, Above, ACE51, ACE96, ACE186, ACE196, ACE960, ActionMedia, BITBUS, COMMputer, CREDIT, Data Pipeline, DVI, ETOX, FaxBACK, Genius, i, i†, i486, i750, i860, ICE, iCEL, ICEVIEW, iCS, iDBP, iDIS, I^2ICE, iLBX, iMDDX, iMMX, Inboard, Insite, Intel, intel, Intel386, intelBOS, Intel Certified, Intelevision, intelligent Identifier, intelligent Programming, Intellec, Intellink, iOSP, iPAT, iPDS, iPSC, iRMK, iRMX, iSBC, iSBX, iSDM, iSXM, Library Manager, MAPNET, MCS, Megachassis, MICROMAINFRAME, MULTICHANNEL, MULTIMODULE, MultiSERVER, ONCE, OpenNET, OTP, Pro750, PROMPT, Promware, QUEST, QueX, Quick-Erase, Quick-Pulse Programming, READY LAN, RMX/80, RUPI, Seamless, SLD, SugarCube, SX, ToolTALK, UPI, VAPI, Visual Edge, VLSiCEL, and ZapCode, and the combination of ICE, iCS, iRMX, iSBC, iSBX, iSXM, MCS, or UPI and a numerical suffix.

MDS is an ordering code only and is not used as a product name or trademark. MDS® is a registered trademark of Mohawk Data Sciences Corporation.

CHMOS and HMOS are patented processes of Intel Corp.

Intel Corporation and Intel's FASTPATH are not affiliated with Kinetics, a division of Excelan, Inc. or its FASTPATH trademark or products.

Additional copies of this manual or other Intel literature may be obtained from:

Intel Corporation
Literature Sales
P.O. Box 7641
Mt. Prospect, IL 60056-7641

©INTEL CORPORATION 1990

CG-101790

CUSTOMER SUPPORT

INTEL'S COMPLETE SUPPORT SOLUTION WORLDWIDE

Customer Support is Intel's complete support service that provides Intel customers with hardware support, software support, customer training, consulting services and network management services. For detailed information contact your local sales offices.

After a customer purchases any system hardware or software product, service and support become major factors in determining whether that product will continue to meet a customer's expectations. Such support requires an international support organization and a breadth of programs to meet a variety of customer needs. As you might expect, Intel's customer support is extensive. It can start with assistance during your development effort to network management. 100 Intel sales and service offices are located worldwide – in the U.S., Canada, Europe and the Far East. So wherever you're using Intel technology, our professional staff is within close reach.

HARDWARE SUPPORT SERVICES

Intel's hardware maintenance service, starting with complete on-site installation will boost your productivity from the start and keep you running at maximum efficiency. Support for system or board level products can be tailored to match your needs, from complete on-site repair and maintenance support to economical carry-in or mail-in factory service.

Intel can provide support service for not only Intel systems and emulators, but also support for equipment in your development lab or provide service on your product to your end-user/customer.

SOFTWARE SUPPORT SERVICES

Software products are supported by our Technical Information Service (TIPS) that has a special toll free number to provide you with direct, ready information on known, documented problems and deficiencies, as well as work-arounds, patches and other solutions.

Intel's software support consists of two levels of contracts. Standard support includes TIPS (Technical Information Phone Service), updates and subscription service (product-specific troubleshooting guides and; *COMMENTS Magazine*). Basic support consists of updates and the subscription service. Contracts are sold in environments which represent product groupings (e.g., iRMX® environment).

NETWORK SERVICE AND SUPPORT

Today's broad spectrum of powerful networking capabilities are only as good as the customer support provided by the vendor. Intel offers network services and support structured to meet a wide variety of end-user computing needs. From a ground up design of your network's physical and logical design to implementation, installation and network wide maintenance. From software products to turn-key system solutions; Intel offers the customer a complete networked solution. With over 10 years of network experience in both the commercial and Government arena; network products, services and support from Intel provide you the most optimized network offering in the industry.

CONSULTING SERVICES

Intel provides field system engineering consulting services for any phase of your development or application effort. You can use our system engineers in a variety of ways ranging from assistance in using a new product, developing an application, personalizing training and customizing an Intel product to providing technical and management consulting. Systems Engineers are well versed in technical areas such as microcommunications, real-time applications, embedded microcontrollers, and network services. You know your application needs; we know our products. Working together we can help you get a successful product to market in the least possible time.

CUSTOMER TRAINING

Intel offers a wide range of instructional programs covering various aspects of system design and implementation. In just three to ten days a limited number of individuals learn more in a single workshop than in weeks of self-study. For optimum convenience, workshops are scheduled regularly at Training Centers worldwide or we can take our workshops to you for on-site instruction. Covering a wide variety of topics, Intel's major course categories include: architecture and assembly language, programming and operating systems, BITBUS™ and LAN applications.

intel®

DATA SHEET DESIGNATIONS

Intel uses various data sheet markings to designate each phase of the document as it relates to the product. The marking appears in the upper, right-hand corner of the data sheet. The following is the definition of these markings:

Data Sheet Marking	Description
Product Preview	Contains information on products in the design phase of development. Do not finalize a design with this information. Revised information will be published when the product becomes available.
Advanced Information	Contains information on products being sampled or in the initial production phase of development.*
Preliminary	Contains preliminary information on new products in production.*
No Marking	Contains information on products in full production.*

*Specifications within these data sheets are subject to change without notice. Verify with your local Intel sales office that you have the latest data sheet before finalizing a design.

80186/188/C186/C188 Data Sheets 1

80186 Development Support Tools 2

80960KA/KB Product Overview and Data Sheets 3

80960CA Product Overview and Data Sheets 4

80960MC Product Overview and Data Sheets 5

80960SA/SB Data Sheet 6

Memories & Peripherals Data Sheets 7

80960 Development Support Tools 8

376™ Embedded Processor & Peripherals Data Sheets 9

Data Sheets

80186 Development
Support Tools

80960KA/KB Product
Overview and Data Sheets

80960CA Product Overview
and Data Sheets

80960MC Product Overview
and Data Sheets

80960SA/SB Data Sheet

Memories & Peripherals
Data Sheets

80960 Development
Support Tools

376™ Embedded
Processor & Peripherals
Data Sheets

376™ Development Support Tools

10

Table of Contents

Alphanumeric Index xiii

80186 FAMILY

Chapter 1

80186/188/C186/C188 DATA SHEETS

80186 High Integration 16-Bit Microprocessor 1-1
80C186 CHMOS High Integration 16-Bit Microprocessor 1-59
80C186EB -16, -13, -8, 16-Bit High-Integration Embedded Processor 1-128
80C187 80-Bit Math Coprocessor 1-188
80188 High Integration 8-Bit Microprocessor 1-218
80C188 CHMOS High Integration 16-Bit Microprocessor 1-277
80C188EB-16, -13, -8 16-Bit High-Integration Embedded Processor 1-349
82188 Integrated Bus Controller for 8086, 8088, 80186, 80188 Processors 1-409
EV80C186 Evaluation Board 1-426

Chapter 2

80186 DEVELOPMENT SUPPORT TOOLS

8086/80186 Software Development Packages 2-1
iPAT Performance Analysis Tool 2-8
I2ICE In-Circuit Emulation System 2-12
AEDIT Source Code and Text Editor 2-16
iC-86/286 C Compiler 2-18
ICE-186 and ICE-188 In-Circuit Emulators 2-22
ICE-186EB and ICE-188EB In-Circuit Emulators 2-25

80960 FAMILY

Chapter 3

80960KA/KB Product Overview 3-1

80960KA/KB DATA SHEETS

80960KA Embedded 32-Bit Processor 3-9
80960KB Embedded 32-Bit Processor with Integrated Floating-Point Unit 3-56

Chapter 4

80960CA Product Overview 4-1

80960CA DATA SHEET

80960CA-40, -33, -25, -16 32-Bit High Performance Embedded Processor 4-39

Chapter 5

80960MC Product Overview 5-1

80960MC DATA SHEETS

80960MC Embedded 32-Bit Microprocessor with Integrated Floating-Point Unit and Memory Management Unit 5-9
M82965 Fault Tolerant Bus Extension Unit 5-47

Chapter 6

80960SA/80960SB Embedded 32-Bit Processors with 16-Bit Burst Data Bus 6-1

MEMORIES AND PERIPHERALS

Chapter 7

DATA SHEETS

85C960 1-Micron CHMOS 80960 K-Series Bus Control microPLD 7-1
27960CX Pipelined Burst Access 1M (128K x 8) CHMOS EPROM 7-19
27960KX Burst Access 1M (128K x 8) CHMOS EPROM 7-40
82596CA High-Performance 32-Bit Local Area Network Coprocessor 7-59

DEVELOPMENT SUPPORT TOOLS

Chapter 8

80960 Software Development Support 8-1
EXV960MC Execution Vehicle 8-7

Table of Contents (Continued)

ICE-960KB In-Circuit Emulator 8-9
ICE-960MC In-Circuit Emulator 8-15
QT960 Evaluation and Prototyping Board 8-23
DB960CADIC In-Circuit Debugger 8-26
SIM960CA Performance Simulator 8-33
80960SA/SB Development Support 8-36
iRMK™ 960 Real-Time Kernel 8-43

376™ EMBEDDED PROCESSOR

Chapter 9

376™ AND PERIPHERALS DATA SHEETS

376 High Performance 32-Bit Embedded Processor 9-1
82370 Integrated System Peripheral 9-96
387 SX Math Coprocessor 9-222
82355 Bus Master Interface Controller (BMIC) 9-223
82596DX and 82596SX High-Performance 32-Bit Local Area Network Coprocessor 9-224
TRANS 186-376 Assembly Code Translator 9-225

376™ DEVELOPMENT TOOLS

Chapter 10

Intel386/i486 Family Development Support 10-1
Intel386 Family of In-Circuit Emulators 10-11
Intel 376 Family Development 10-37

Alphanumeric Index

27960CX Pipelined Burst Access 1M (128K x 8) CHMOS EPROM 7-19
27960KX Burst Access 1M (128K x 8) CHMOS EPROM 7-40
376 High Performance 32-Bit Embedded Processor 9-1
387 SX Math Coprocessor 9-222
80186 High Integration 16-Bit Microprocessor 1-1
80188 High Integration 8-Bit Microprocessor 1-218
8086/80186 Software Development Packages 2-1
80960 Software Development Support 8-1
80960CA Product Overview 4-1
80960CA-40, -33, -25, -16 32-Bit High Performance Embedded Processor 4-39
80960KA Embedded 32-Bit Processor 3-9
80960KA/KB Product Overview 3-1
80960KB Embedded 32-Bit Processor with Integrated Floating-Point Unit 3-56
80960MC Embedded 32-Bit Microprocessor with Integrated Floating-Point Unit and Memory Management Unit 5-9
80960MC Product Overview 5-1
80960SA/80960SB Embedded 32-Bit Processors with 16-Bit Burst Data Bus 6-1
80960SA/SB Development Support 8-36
80C186 CHMOS High Integration 16-Bit Microprocessor 1-59
80C186EB -16, -13, -8, 16-Bit High-Integration Embedded Processor 1-128
80C187 80-Bit Math Coprocessor 1-188
80C188 CHMOS High Integration 16-Bit Microprocessor 1-277
80C188EB-16, -13, -8 16-Bit High-Integration Embedded Processor 1-349
82188 Integrated Bus Controller for 8086, 8088, 80186, 80188 Processors 1-409
82355 Bus Master Interface Controller (BMIC) 9-223
82370 Integrated System Peripheral 9-96
82596CA High-Performance 32-Bit Local Area Network Coprocessor 7-59
82596DX and 82596SX High-Performance 32-Bit Local Area Network Coprocessor 9-224
85C960 1-Micron CHMOS 80960 K-Series Bus Control microPLD 7-1
AEDIT Source Code and Text Editor 2-16
DB960CADIC In-Circuit Debugger 8-26
EV80C186 Evaluation Board 1-426
EXV960MC Execution Vehicle 8-7
I2ICE In-Circuit Emulation System 2-12
iC-86/286 C Compiler 2-18
ICE-186 and ICE-188 In-Circuit Emulators 2-22
ICE-186EB and ICE-188EB In-Circuit Emulators 2-25
ICE-960KB In-Circuit Emulator 8-9
ICE-960MC In-Circuit Emulator 8-15
Intel 376 Family Development 10-37
Intel386 Family of In-Circuit Emulators 10-11
Intel386/i486 Family Development Support 10-1
iPAT Performance Analysis Tool 2-8
iRMK™ 960 Real-Time Kernel 8-43
M82965 Fault Tolerant Bus Extension Unit 5-47
QT960 Evaluation and Prototyping Board 8-23
SIM960CA Performance Simulator 8-33
TRANS 186-376 Assembly Code Translator 9-225

80960MC Embedded 32-Bit Microprocessor with Integrated Floating-Point Unit and Memory Management Unit 5-9
80960MC Product Overview 5-1
80960SA/80960SB Embedded 32-Bit Processors with 16-Bit Burst Data Bus 6-1
80960SA/SB Development Support 6-35
80C186 CHMOS High Integration 16-Bit Microprocessor 1-59
80C186EB -16, -13, -8, 16-Bit High-Integration Embedded Processor 1-128
80C187 80-Bit Math Coprocessor 1-188
80C188 CHMOS High Integration 16-Bit Microprocessor 1-277
80C188EB-16, -13, -8 16-Bit High-Integration Embedded Processor 1-349
82188 Integrated Bus Controller for 8086, 8088, 80186, 80188 Processors 1-409
82355 Bus Master Interface Controller (BMIC) 9-223
82370 Integrated System Peripheral 9-56
82596CA High-Performance 32-Bit Local Area Network Coprocessor 7-59
82596DX and 82596SX High-Performance 32-Bit Local Area Network Coprocessor 9-224
85C860 1-Micron CHMOS 80960 K-Series Bus Control microPLD 7-1
AEDIT Source Code and Text Editor 2-16
D3960CADIC In-Circuit Debugger 8-28
EV80C188 Evaluation Board 1-429
EXV960MC Execution Vehicle 6-7
ICE Jr. In-Circuit Emulation System 2-12
IC-86/286 C Compiler 2-16
ICE-186 and ICE-188 In-Circuit Emulators 2-22
ICE-186EB and ICE-188EB In-Circuit Emulators 2-25
ICE-960KB In-Circuit Emulator 8-9
ICE-960MC In-Circuit Emulator 8-15
Intel 376 Family Development 10-37
Intel386 Family of In-Circuit Emulators 10-11
Intel386/i486 Family Development Support 10-1
iPAT Performance Analysis Tool 2-8
iRMK™ 960 Real-Time Kernel 8-43
M82355 Fault Tolerant Bus Extension Unit 5-47
QT960 Evaluation and Prototyping Board 8-29
SIM960CA Performance Simulator 8-33
TRANS 186-376 Assembly Code Translator 9-225

80186/188/C186/C188 Data Sheets

1

80186/188/C186/C188

Data Sheets

1

- **Available in 10 MHz (80186-10) and 8 MHz (80186) Versions**
- **High-Performance Processor**
  - **— 4 MByte/Sec Bus Bandwidth Interface @ 8 MHz**
  - **— 5 MByte/Sec Bus Bandwidth Interface @ 10 MHz**
- **Direct Addressing Capability to 1 MByte of Memory and 64 KByte I/O**
- **Through 8087 Interface**
- **Available in 68 Pin:**
  - **— Plastic Leaded Chip Carrier (PLCC)**
  - **— Ceramic Pin Grid Array (PGA)**
  - **— Ceramic Leadless Chip Carrier (LCC)**

  (See Packaging Outlines and Dimensions, Order #231369)
- **Available in EXPRESS**
  - **— Standard Temperature with Burn-In**
  - **— Extended Temperature Range (−40°C to +85°C)**

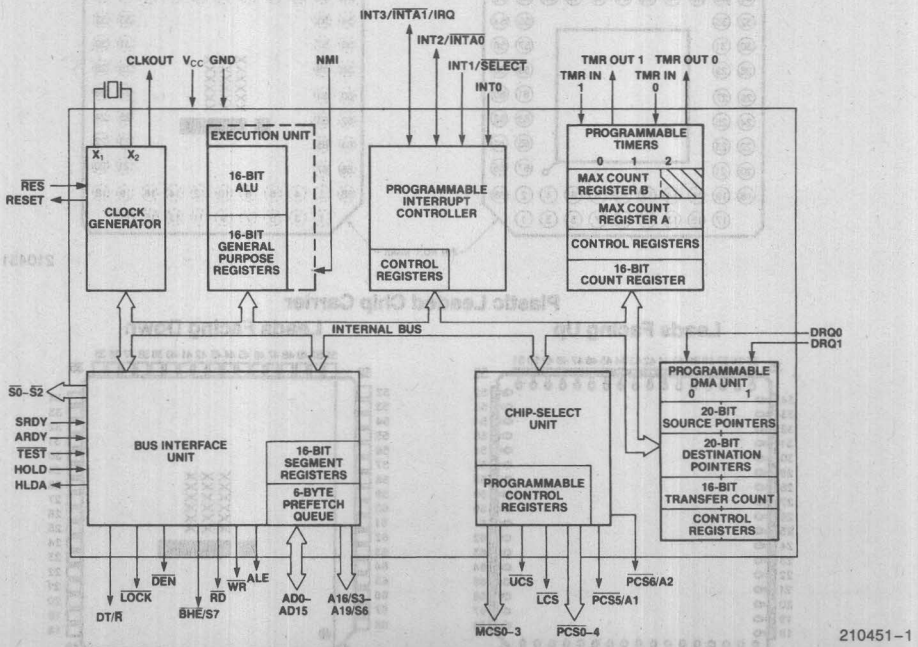


Figure 1. 80186 Block Diagram

October 1989
Order Number: 210451-011

The Intel 80186 is a highly integrated 16-bit microprocessor. The 80186 effectively combines 15–20 of the most common 8086 system components onto one. The 80186 provides two times greater throughput than the standard 5 MHz 8086. The 80186 is upward compatible with 8086 and 8088 software and adds 10 new instruction types to the existing set.

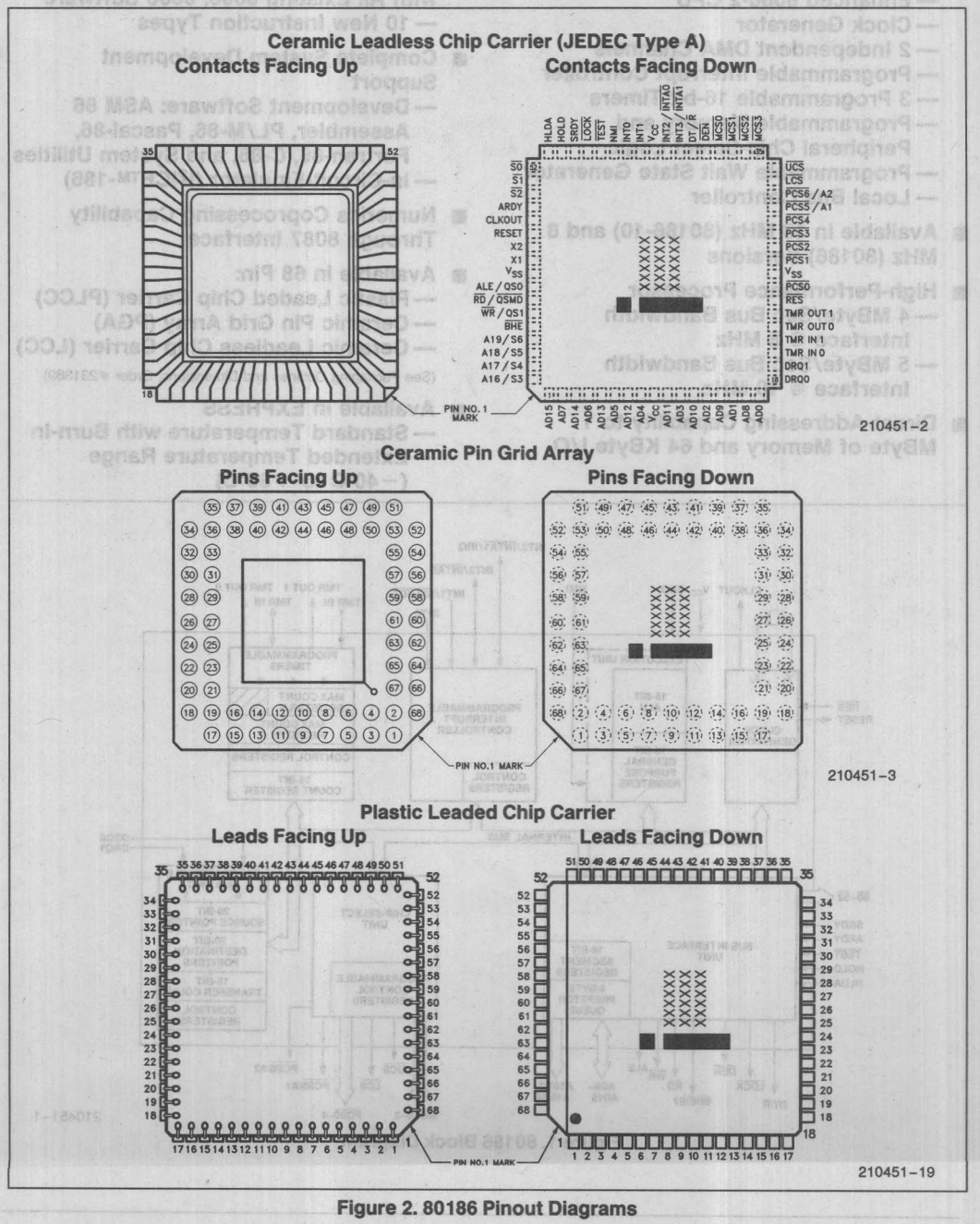


Figure 2. 80186 Pinout Diagrams

Table 1. 80186 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	9 43	I	**System Power:** +5 volt power supply.
V_{SS}	26 60	I	System Ground.
RESET	57	O	Reset Output indicates that the 80186 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal.
X1 X2	59 58	I O	Crystal Inputs X1 and X2 provide external connections for a fundamental mode parallel resonant crystal for the internal oscillator. Instead of using a crystal, an external clock may be applied to X1 while minimizing stray capacitance on X2. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	Clock Output provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT.
$\overline{RES}$	24	I	An active $\overline{RES}$ causes the 80186 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80186 clock. The 80186 begins fetching instructions approximately 6½ clock cycles after $\overline{RES}$ is returned HIGH. For proper initialization, V_{CC} must be within specifications and the clock signal must be stable for more than 4 clocks with $\overline{RES}$ held LOW. $\overline{RES}$ is internally synchronized. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network.
$\overline{TEST}$	47	I/O	$\overline{TEST}$ is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when "WAIT" execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80186 is waiting for $\overline{TEST}$, interrupts will be serviced. During power-up, active $\overline{RES}$ is required to configure $\overline{TEST}$ as an input. This pin is synchronized internally.
TMR IN 0 TMR IN 1	20 21	I I	Timer Inputs are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized.
TMR OUT 0 TMR OUT 1	22 23	O O	Timer outputs are used to provide single pulse or continous waveform generation, depending upon the timer mode selected.
DRQ0 DRQ1	18 19	I I	DMA Request is asserted HIGH by an external device when it is ready for DMA Channel 0 or 1 to perform a transfer. These signals are level-triggered and internally synchronized.
NMI	46	I	The Non-Maskable Interrupt input causes a Type 2 interrupt. An NMI transition from LOW to HIGH is latched and synchronized internally, and initiates the interrupt at the next instruction boundary. NMI must be asserted for at least one clock. The Non-Maskable Interrupt cannot be avoided by programming.
INT0 INT1/$\overline{SELECT}$ INT2/$\overline{INTA0}$ INT3/$\overline{INTA1}$/IRQ	45 44 42 41	I I I/O I/O	Maskable Interrupt Requests can be requested by activating one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowledged. When Slave Mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).

Table 1. 80186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
A19/S6 A18/S5 A17/S4 A16/S3	65 66 67 68	O O O O	Address Bus Outputs (16–19) and Bus Cycle Status (3–6) indicate the four most significant address bits during T_1. These signals are active HIGH. During T_2, T_3, T_W, and T_4, the S6 pin is LOW to indicate a CPU-initiated bus cycle or HIGH to indicate a DMA-initiated bus cycle. During the same T-states, S3, S4, and S5 are always LOW. The status pins float during bus HOLD or RESET.
AD15 AD14 AD13 AD12 AD11 AD10 AD9 AD8 AD7 AD6 AD5 AD4 AD3 AD2 AD1 AD0	1 3 5 7 10 12 14 16 2 4 6 8 11 13 15 17	I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O	Address/Data Bus (0–15) signals constitute the time multiplexed memory or I/O address (T_1) and data (T_2, T_3, T_W, and T_4) bus. The bus is active HIGH. A_0 is analogous to $\overline{BHE}$ for the lower byte of the data bus, pins D_7 through D_0. It is LOW during T_1 when a byte is to be transferred onto the lower portion of the bus in memory or I/O operations.
$\overline{BHE}$/S7	64	O	During T_1 the Bus High Enable signal should be used to determine if data is to be enabled onto the most significant half of the data bus; pins D_{15}–D_8. $\overline{BHE}$ is LOW during T_1 for read, write, and interrupt acknowledge cycles when a byte is to be transferred on the higher half of the bus. The S_7 status information is available during T_2, T_3, and T_4. S_7 is logically equivalent to $\overline{BHE}$. $\overline{BHE}$/S7 floats during HOLD.

$\overline{BHE}$ and A0 Encodings

$\overline{BHE}$ Value	A0 Value	Function
0	0	Word Transfer
0	1	Byte Transfer on upper half of data bus (D15–D8)
1	0	Byte Transfer on lower half of data bus (D_7–D_0)
1	1	Reserved

ALE/QS0	61	O	Address Latch Enable/Queue Status 0 is provided by the 80186 to latch the address. ALE is active HIGH. Addresses are guaranteed to be valid on the trailing edge of ALE. The ALE rising edge is generated off the rising edge of the CLKOUT immediately preceding T_1 of the associated bus cycle, effectively one-half clock cycle earlier than in the 8086. The trailing edge is generated off the CLKOUT rising edge in T_1 as in the 8086. Note that ALE is never floated.
$\overline{WR}$/QS1	63	O	Write Strobe/Queue Status 1 indicates that the data on the bus is to be written into a memory or an I/O device. $\overline{WR}$ is active for T_2, T_3, and T_W of any write cycle. It is active LOW, and floats during HOLD. When the 80186 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction.

QS1	QS0	Queue Operation
0	0	No queue operation
0	1	First opcode byte fetched from the queue
1	1	Subsequent byte fetched from the queue
1	0	Empty the queue

Table 1. 80186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{RD}$/QSMD	62	I/O	Read Strobe is an active LOW signal which indicates that the 80186 is performing a memory or I/O read cycle. It is guaranteed not to go LOW before the A/D bus is floated. An internal pull-up ensures that $\overline{RD}$ is HIGH during RESET. Following RESET the pin is sampled to determine whether the 80186 is to provide ALE, $\overline{RD}$, and $\overline{WR}$, or queue status information. To enable Queue Status Mode, $\overline{RD}$ must be connected to GND. $\overline{RD}$ will float during bus HOLD.
ARDY	55	I	Asynchronous Ready informs the 80186 that the addressed memory space or I/O device will complete a data transfer. The ARDY pin accepts a rising edge that is asynchronous to CLKOUT, and is active HIGH. The falling edge of ARDY must be synchronized to the 80186 clock. Connecting ARDY HIGH will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the SRDY pin.
SRDY	49	I	Synchronous Ready informs the 80186 that the addressed memory space or I/O device will complete a data transfer. The SRDY pin accepts an active-HIGH input synchronized to CLKOUT. The use of SRDY allows a relaxed system timing over ARDY. This is accomplished by elimination of the one-half clock cycle required to internally synchronize the ARDY input signal. Connecting SRDY high will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the ARDY pin.
$\overline{LOCK}$	48	O	$\overline{LOCK}$ output indicates that other system bus masters are not to gain control of the system bus while $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is requested by the LOCK prefix instruction and is activated at the beginning of the first data cycle associated with the instruction following the LOCK prefix. It remains active until the completion of that instruction. No instruction prefetching will occur while $\overline{LOCK}$ is asserted. When executing more than one LOCK instruction, always make sure there are 6 bytes of code between the end of the first LOCK instruction and the start of the second LOCK instruction. $\overline{LOCK}$ is driven HIGH for one clock during RESET and then floated.
$\overline{S0}$	52	O	Bus cycle status $\overline{S0}$–$\overline{S2}$ are encoded to provide bus-transaction information:
$\overline{S1}$	53	O	
$\overline{S2}$	54	O	

80186 Bus Cycle Status Information

$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	Bus Cycle Initiated
0	0	0	Interrupt Acknowledge
0	0	1	Read I/O
0	1	0	Write I/O
0	1	1	Halt
1	0	0	Instruction Fetch
1	0	1	Read Data from Memory
1	1	0	Write Data to Memory
1	1	1	Passive (no bus cycle)

The status pins float during HOLD.
$\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator.

			This line is not floated during bus HOLD. The address range activating $\overline{LCS}$ is software programmable.
$\overline{MCS0}$ $\overline{MCS1}$ $\overline{MCS2}$ $\overline{MCS3}$	38 37 36 35	O O O O	Mid-Range Memory Chip Select signals are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines are not floated during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable.
$\overline{PCS0}$ $\overline{PCS1}$ $\overline{PCS2}$ $\overline{PCS3}$ $\overline{PCS4}$	25 27 28 29 30	O O O O O	Peripheral Chip Select signals 0–4 are active LOW when a reference is made to the defined peripheral area (64K byte I/O space). These lines are not floated during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	Peripheral Chip Select 5 or Latched A1 may be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software-programmable. $\overline{PCS5}$/A1 does not float during bus HOLD. When programmed to provide latched A1, this pin will retain the previously latched value during HOLD.
$\overline{PCS6}$/A2	32	O	Peripheral Chip Select 6 or Latched A2 may be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software programmable. $\overline{PCS6}$/A2 does not float during bus HOLD. When programmed to provide latched A2, this pin will retain the previously latched value during HOLD.
DT/$\overline{R}$	40	O	Data Transmit/Receive controls the direction of data flow through an external data bus transceiver. When LOW, data is transferred to the 80186. When HIGH the 80186 places write data on the data bus.
$\overline{DEN}$	39	O	Data Enable is provided as a data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access. $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state. During RESET, $\overline{DEN}$ is driven HIGH for one clock, then floated. $\overline{DEN}$ also floats during HOLD.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the 80186. The 80186 is a very high integration 16-bit microprocessor. It combines 15–20 of the most common microprocessor system components onto one chip while providing twice the performance of the standard 8086. The 80186 is object code compatible with the 8086/8088 microprocessors and adds 10 new instruction types to the 8086/8088 instruction set.

80186 BASE ARCHITECTURE

The 8086, 8088, 80186, and 80286 family all contain the same basic set of registers, instructions, and addressing modes.

Register Set

The 80186 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

General Registers

Eight 16-bit general purpose registers may be used for arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

Segment Registers

Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers

Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Status and Control Registers

Two 16-bit special purpose registers record or alter certain aspects of the 80186 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

Status Word Description

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80186 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

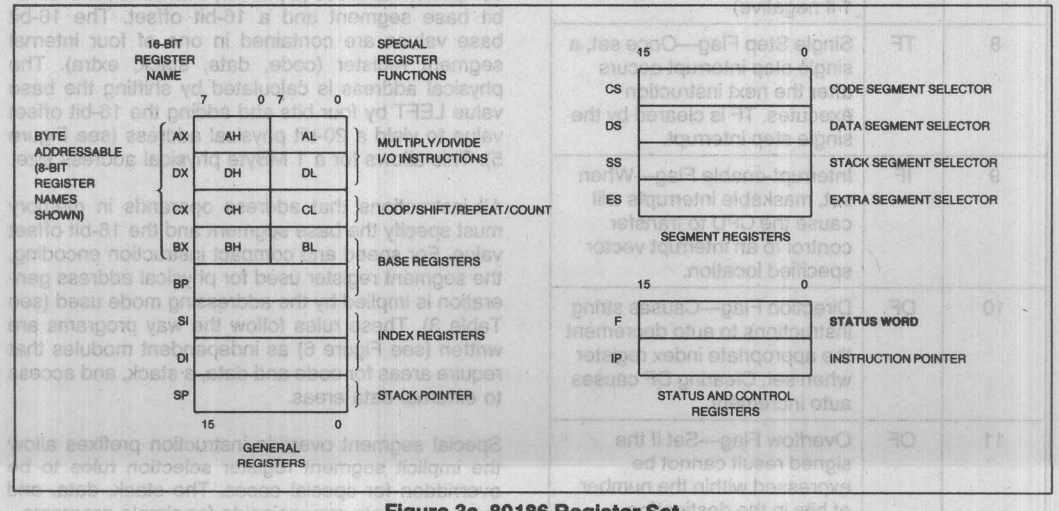


Figure 3a. 80186 Register Set

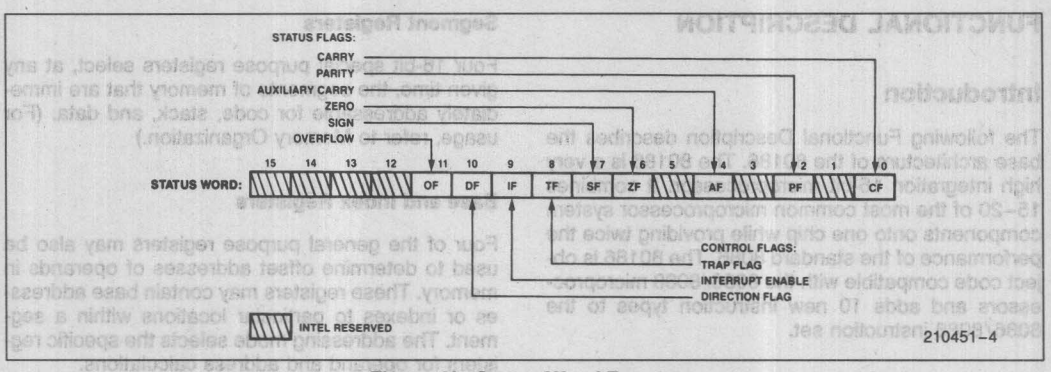


Figure 3b. Status Word Format

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag—Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80186 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment register (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack
ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero
LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word
FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{TEST}}$ pin active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. 80186 Instruction Set

CONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal
JAE/JNB	Jump if above or equal/not below
JB/JNAE	Jump if below/not above nor equal
JBE/JNA	Jump if below or equal/not above
JC	Jump if carry
JE/JZ	Jump if equal/zero
JG/JNLE	Jump if greater/not less nor equal
JGE/JNL	Jump if greater or equal/not less
JL/JNGE	Jump if less/not greater nor equal
JLE/JNG	Jump if less or equal/not greater
JNC	Jump if not carry
JNE/JNZ	Jump if not equal/not zero
JNO	Jump if not overflow
JNP/JPO	Jump if not parity/parity odd
JNS	Jump if not sign

JO	Jump if overflow
JP/JPE	Jump if parity/parity even
JS	Jump if sign
UNCONDITIONAL TRANSFERS	
CALL	Call procedure
RET	Return from procedure
JMP	Jump
ITERATION CONTROLS	
LOOP	Loop
LOOPE/LOOPZ	Loop if equal/zero
LOOPNE/LOOPNZ	Loop if not equal/not zero
JCXZ	Jump if register CX = 0
INTERRUPTS	
INT	Interrupt
INTO	Interrupt if overflow
IRET	Interrupt return

Figure 4. 80186 Instruction Set (Continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

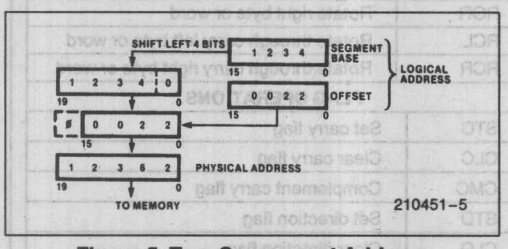


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

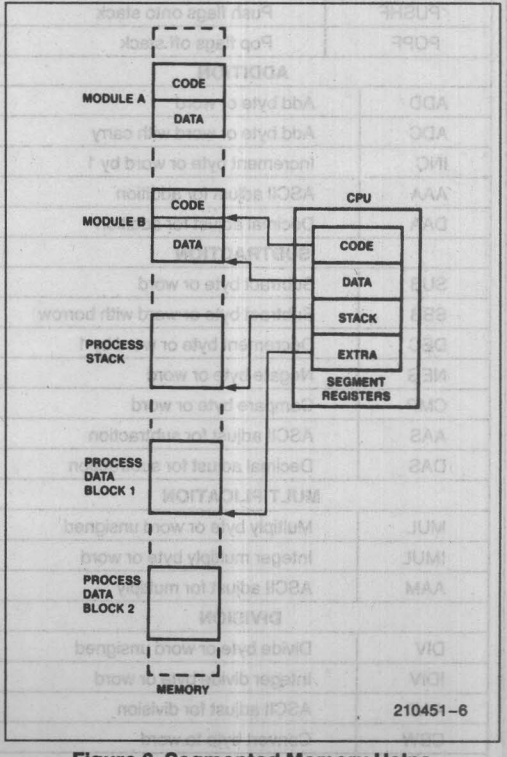


Figure 6. Segmented Memory Helps Structure Software

Addressing Modes

The 80186 provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an Index register.
- *Based indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

Data Types

The 80186 directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using an 8087 Numeric Data Coprocessor with the 80186.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or a 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.
- *Floating Point:* A signed 32-, 64-, or 80-bit real number representation. (Floating point operands are supported using an 8087 Numeric Data Coprocessor with the 80186.)

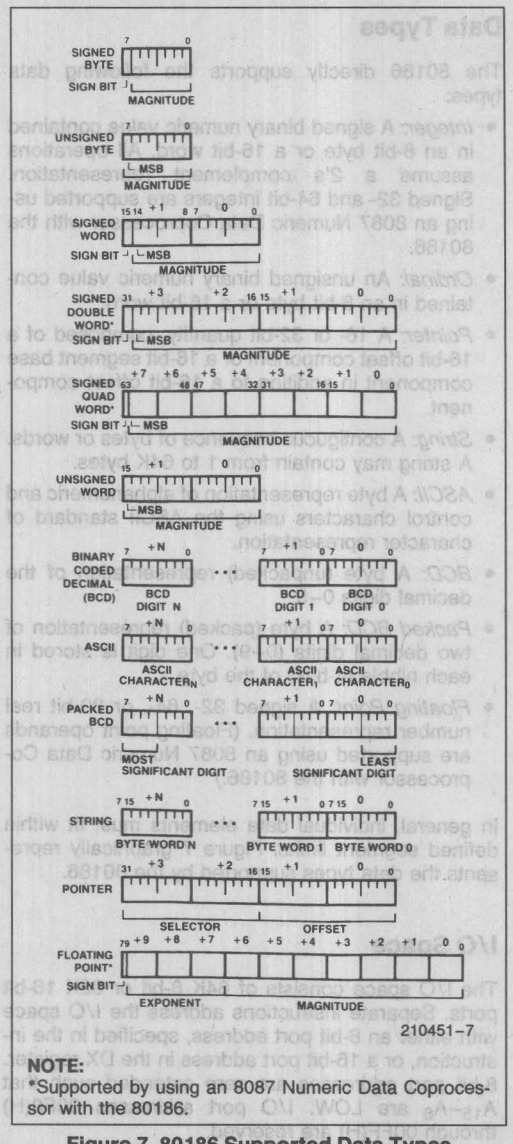
In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the 80186.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}–A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.



NOTE:
*Supported by using an 8087 Numeric Data Coprocessor with the 80186.

Figure 7. 80186 Supported Data Types

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by executing an ESC instruction with the ESC trap bit set in the relocation register, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present. In all other cases, the return address from an exception will point at the instruction immediately following the instruction causing the exception.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. Table 4 shows the 80186 predefined types and default priority levels. For each interrupt, an 8-bit vector must be supplied to the 80186 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. In addition, internal peripherals and noncascaded external interrupts will generate their own vectors through the internal interrupt controller. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80186 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

Those pre-defined 80186 interrupts which cannot be masked by programming are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

SINGLE-STEP INTERRUPT (TYPE 1)

Generated after most instructions if the TF flag is set. Interrupts will not be generated after prefix instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)

An external interrupt source which cannot be masked.

Table 4. 80186 Interrupt Vectors

Interrupt Name	Vector Type	Vector Address	Default Priority	Related Instructions	Applicable Notes
Divide Error Exception	0	00H	1	DIV, IDIV	1
Single Step Interrupt	1	04H	1A	All	2
Non-Maskable Interrupt (NMI)	2	08H	1	All	
Breakpoint Interrupt	3	0CH	1	INT	1
INTO Detected Overflow Exception	4	10H	1	INTO	1
Array Bounds Exception	5	14H	1	BOUND	1
Unused Opcode Exception	6	18H	1	Undefined Opcodes	1
ESC Opcode Exception	7	1CH	1	ESC Opcodes (Coprocessor)	1, 3
Timer 0 Interrupt	8	20H	2A		4, 5
Timer 1 Interrupt	18	48H	2B		4, 5
Timer 2 Interrupt	19	4CH	2C		4, 5
Reserved	9	24H	3		
DMA 0 Interrupt	10	28H	4		5
DMA 1 Interrupt	11	2CH	5		
INT0 Interrupt	12	30H	6		
INT1 Interrupt	13	34H	7		
INT2 Interrupt	14	38H	8		
INT3 Interrupt	15	3CH	9		
Reserved	16, 17	40H, 44H			
Reserved	20–31	50H–7CH			

NOTES:
Default priorities for the interrupt sources are used only if the user does not program each source to a unique priority level.
1. Generated as a result of an instruction execution.
2. Performed in same manner as 8086.
3. An ESC (coprocessor) opcode will cause a trap only if the proper bit is set in the peripheral control block relocation register.
4. All three timers constitute one source of request to the interrupt controller. As such, they share the same priority level with respect to other interrupt sources. However, the timers have a defined priority order among themselves (2A > 2B > 2C).
5. The vector type numbers for these sources are programmable in Slave Mode.

BREAKPOINT INTERRUPT (TYPE 3)

A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INTO DETECTED OVERFLOW EXCEPTION (TYPE4)

Generated during an INTO instruction if the OF bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)

Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)

Generated if execution is attempted on undefined opcodes.

ESCAPE OPCODE EXCEPTION (TYPE 7)

Generated if execution is attempted of ESC opcodes (D8H–DFH). This exception will only be generated if a bit in the relocation register is set. The return address of this exception will point to the ESC instruction causing the exception. If a segment override prefix preceded the ESC instruction, the return address will point to the segment override prefix.

Hardware-generated interrupts are divided into two groups: maskable interrupts and non-maskable interrupts. The 80186 provides maskable hardware interrupt request pins INT0–INT3. In addition, maskable interrupts may be generated by the 80186

return re-enables interrupts, and another interrupt is pending, the 80186 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Non-Maskable Interrupt Request (NMI)

A non-maskable interrupt (NMI) is also provided. This interrupt is serviced regardless of the state of the IF bit. A typical use of NMI would be to activate a power failure routine. The activation of this input causes an interrupt with an internally supplied vector value of 2. No external interrupt acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced.

Single-Step Interrupt

The 80186 has an internal interrupt that allows programs to execute one instruction at a time. It is called the single-step interrupt and is controlled by the single-step flag bit (TF) in the Status Word. Once this bit is set, an internal single-step interrupt will occur after the next instruction has been executed. The interrupt clears the TF bit and uses an internally supplied vector of 1. The IRET instruction is used to set the TF bit and transfer control to the next instruction to be single-stepped.

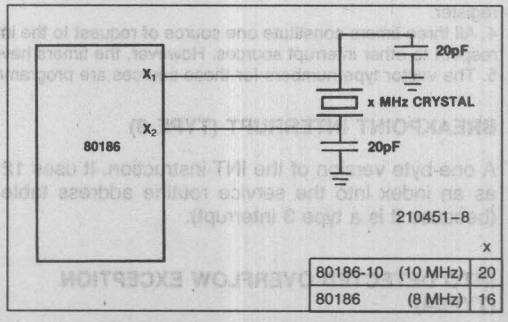
Initialization and Processor Reset

Processor initialization is accomplished by driving the $\overline{RES}$ input pin LOW. $\overline{RES}$ must be LOW during power-up to ensure proper device initialization. $\overline{RES}$ forces the 80186 to terminate all execution and local bus activity. No instruction or bus activity will occur as long as $\overline{RES}$ is active. After $\overline{RES}$ becomes inactive and an internal processing interval elapses, the 80186 begins execution with the instruction at physical location FFFF0(H). $\overline{RES}$ also sets some registers to predefined values as shown in Table 5.

The 80186 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The oscillator circuit of the 80186 is designed to be used with a parallel resonant fundamental mode crystal. This is used as the time base for the 80186. The crystal frequency selected will be double the CPU clock frequency. Use of an LC or RC circuit is not recommended with this oscillator. If an external oscillator is used, it can be connected directly to the input pin X1 in lieu of a crystal. The output of the oscillator is not directly available outside the 80186. The recommended crystal configuration is shown in Figure 8.



80186-10	(10 MHz)	20
80186	(8 MHz)	16

Figure 8. Recommended 80186 Crystal Configuration

Intel recommends the following values for crystal selection parameters:

Temperature Range:	0 to 70°C
ESR (Equivalent Series Resistance):	30Ω max
C_0 (Shunt Capacitance of Crystal):	7.0 pf max
C_1 (Load Capacitance):	20 pf ± 2 pf
Drive Level:	1 mW max

Clock Generator

The 80186 clock generator provides the 50% duty cycle processor clock for the 80186. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the 80186. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The 80186 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3, and again in the middle of each T_W until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used for full synchronization of a rising ARDY signal. A high-to-low transition on ARDY may be used as an indication of the not ready condition but it must be performed synchronously to CLKOUT **either** in the middle of T_2, T_3, or T_W, **or** at the falling edge of T_3 or T_W.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3 and again at the end of each T_W until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated. This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the 80186, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

RESET Logic

The 80186 provides both a $\overline{RES}$ input pin and a synchronized RESET output pin for use with other system components. The $\overline{RES}$ input pin on the 80186 is provided with hysteresis in order to facilitate power-on Reset generation via an RC network. RESET output is guaranteed to remain active for at least five clocks given a $\overline{RES}$ input of at least six clocks. RESET may be delayed up to approximately two and one-half clocks behind $\overline{RES}$.

Multiple 80186 processors may be synchronized through the $\overline{RES}$ input pin, since this input resets both the processor and divide-by-two internal counter in the clock generator. In order to ensure that the divide-by-two counters all begin counting at the same time, the active going edge of $\overline{RES}$ must satisfy a 25 ns setup time before the falling edge of the 80186 clock input. In addition, in order to ensure that all CPUs begin executing in the same clock cycle, the reset must satisfy a 25 ns setup time before the rising edge of the CLKOUT signal of all the processors.

LOCAL BUS CONTROLLER

The 80186 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides outputs that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The 80186 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory or I/O to the 80186 or to strobe data from the 80186 to memory or I/O. The ALE line provides a strobe to latch the address when it is valid. The 80186 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The 80186 generates two control signals to be connected to transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

Table 6. Transceiver Control Signals Description

Pin Name	Function
$\overline{DEN}$ (Data Enable)	Enables the output drivers of the transceivers. It is active LOW during memory, I/O, or INTA cycles.
DT/$\overline{R}$ (Data Transmit/ Receive)	Determines the direction of travel through the transceivers. A HIGH level directs data away from the processor during write operations, while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The 80186 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The 80186 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. External circuitry must arbitrate which external device will gain control of the bus when there is more than one alternate local bus master. When the 80186 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$–$\overline{S2}$, $\overline{LOCK}$, AD0–AD15, A16–A19, $\overline{BHE}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The 80186 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is the highest-priority activity request which the processor may receive: higher than instruction fetching or internal DMA cycles. However, if a DMA cycle is in progress, the 80186 will complete the transfer before relinquishing the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency time can be as great as 4 bus cycles. This will occur if a DMA word transfer operation is taking place from an odd address to an odd address. This is a total of 16 clocks or more, if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

Local Bus Controller and Reset

During RESET the local bus controller will perform the following action:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float.

NOTE:
$\overline{RD}$ is also provided with an internal pull-up device to prevent the processor from inadvertently entering Queue Status Mode during RESET.

- Drive $\overline{S0}$–$\overline{S2}$ to the inactive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Float AD0–15, A16–19, $\overline{BHE}$, DT/$\overline{R}$.
- Drive ALE LOW (ALE is never floated).
- Drive HLDA LOW.

INTERNAL PERIPHERAL INTERFACE

All the 80186 integrated peripherals are controlled by 16-bit registers contained within an internal 256-byte control block. The control block may be mapped into either memory or I/O space. Internal logic will recognize control block addresses and respond to bus cycles. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{15-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80186 CPU at any time.

The control block base address is programmed by a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. The control block is effectively an internal chip select range and must abide by all the rules concerning chip selects (the chip select circuitry is discussed later in this data sheet). Any access to the 256 bytes of the control block activates an internal chip select. Other chip selects may overlap the control block only if they are programmed to zero wait states and ignore external ready. In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space. If the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into Slave Mode, and cause the CPU to interrupt upon encountering ESC instructions. At RESET, the relocation register

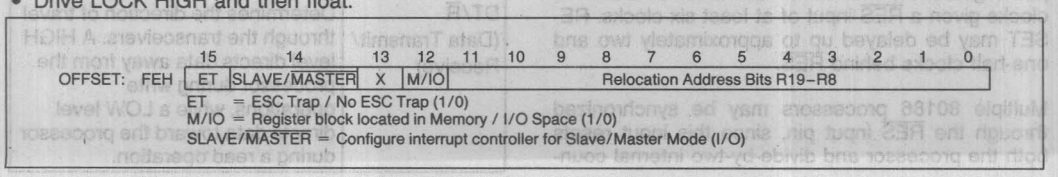


Figure 9. Relocation Register

is set to 20FFH, which maps the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

CHIP-SELECT/READY GENERATION LOGIC

The 80186 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

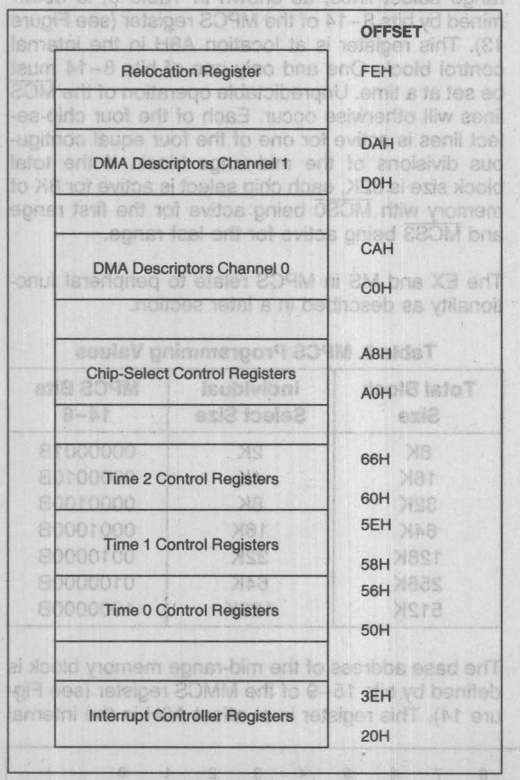


Figure 10. Internal Register Map

Memory Chip Selects

The 80186 provides 6 memory chip select outputs for 3 address areas; upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes, whereas 80186 memory is arranged in words. This means that if, for example, 16 64K x 1 memories are used, the memory block size will be 128K, not 64K.

Upper Memory $\overline{CS}$

The 80186 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the 80186 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0 = R1 = R2 = 0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

The internal generation of any 20-bit address whose upper 16 bits are equal to or greater than the UMCS

value (with bits 0–5 as "0") asserts $\overline{UCS}$. UMCS bits R2–R0 specify the ready mode for the area of memory defined by this chip select register, as explained later.

Lower Memory $\overline{CS}$

The 80186 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0 = R1 = R2 = 0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12) at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After RESET, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will assert $\overline{LCS}$. LMCS register bits R2–R0 specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The 80186 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located within the 80186 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. If the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as described in a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14–8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal

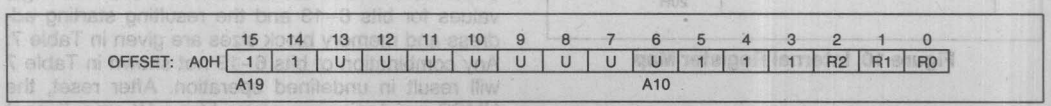


Figure 11. UMCS Register

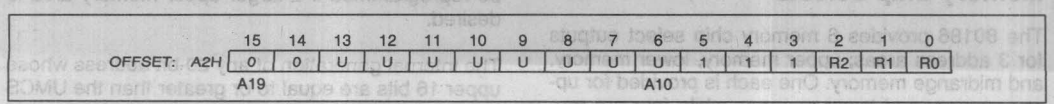


Figure 12. LMCS Register

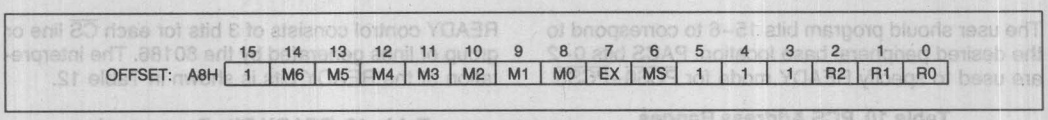


Figure 13. MPCS Register

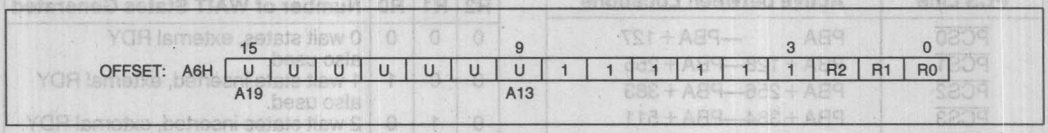


Figure 14. MMCS Register

control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After RESET, the contents of both of these registers are undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

MMCS bits R2–R0 specify READY mode of operation for all four mid-range chip selects.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

Peripheral Chip Selects

The 80186 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a programmable base address. The base address may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the 80186. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1 and A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0 and A1 pins used for selecting internal registers of 8-bit peripheral chips. This simplifies the external hardware because the peripheral registers can be located on even boundaries in I/O or memory space.

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). The register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

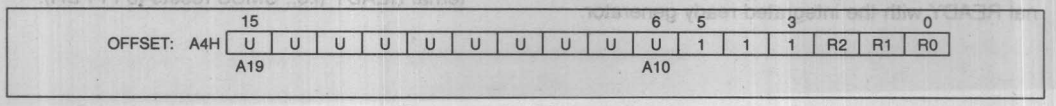


Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

$\overline{PCS}$ Line	Active between Locations
$\overline{PCS0}$	PBA —PBA + 127
$\overline{PCS1}$	PBA + 128—PBA + 255
$\overline{PCS2}$	PBA + 256—PBA + 383
$\overline{PCS3}$	PBA + 384—PBA + 511
$\overline{PCS4}$	PBA + 512—PBA + 639
$\overline{PCS5}$	PBA + 640—PBA + 767
$\overline{PCS6}$	PBA + 768—PBA + 895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 13). The register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After RESET, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space.
	0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided.
	1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 specify the READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The 80186 can generate a READY signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the 80186 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the 80186. The interpretation of the READY bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal ready generator operates in parallel with external READY, not in series if the external READY is used (R2 = 0). For example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon RESET, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to insert 3 wait states in conjunction with external READY (i.e., UMCS resets to FFFBH).

odd addresses. Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer (by one or two depending on byte or word transfers). Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data. This provides a maximum data transfer rate of 1.25 Mword/sec or 2.5 MBytes/sec at 10 MHz.

ters will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

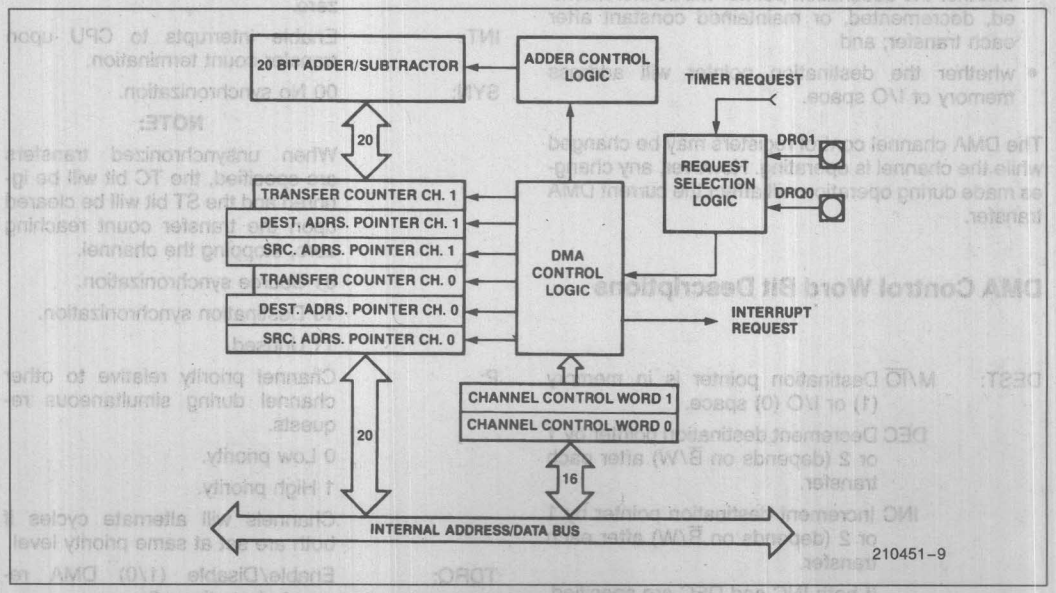


Figure 16. DMA Unit Block Diagram

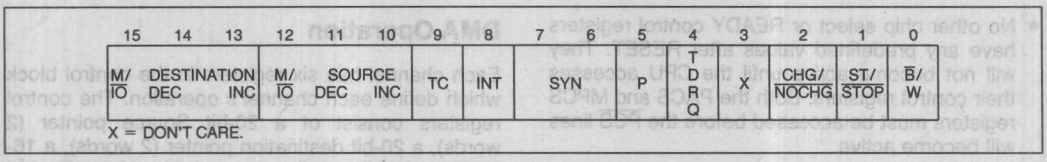


Figure 17. DMA Control Register

DMA Channel Control Word Register

Each DMA Channel Control Word determines the mode of operation for the particular 81086 DMA channel. This register specifies:

- the mode of synchronization;
- whether bytes or words will be transferred;
- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

DEST: M/$\overline{IO}$ Destination pointer is in memory (1) or I/O (0) space.

DEC Decrement destination pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

INC Increment destination pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

If both INC and DEC are specified, the pointer will not change after each cycle.

SOURCE: M/$\overline{IO}$ Source pointer is in memory (1) or I/O (0) space.

DEC Decrement source pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

INC Increment source pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

If both INC and DEC are specified, the pointer will not change after each cycle.

TC: If set, DMA will terminate when the contents of the transfer count register reach zero. The ST/$\overline{STOP}$ bit will also be reset at this point. If cleared, the DMA controller will decrement the transfer count register for each DMA cycle, but DMA transfers will not stop when the transfer count register reaches zero.

INT: Enable interrupts to CPU upon transfer count termination.

SYN: 00 No synchronization.

NOTE:

When unsynchronized transfers are specified, the TC bit will be ignored and the ST bit will be cleared upon the transfer count reaching zero, stopping the channel.

01 Source synchronization.

10 Destination synchronization.

11 Unused.

P: Channel priority relative to other channel during simultaneous requests.

0 Low priority.

1 High priority.

Channels will alternate cycles if both are set at same priority level.

TDRQ: Enable/Disable (1/0) DMA requests from timer 2.

CHG/$\overline{\text{NOCHG}}$: Change/Do not change (1/0) ST/$\overline{\text{STOP}}$ bit. If this bit is set when writing the control word, the ST/$\overline{\text{STOP}}$ bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/$\overline{\text{STOP}}$ bit will not be altered. This bit is not stored; it will always be read as 0.

ST/$\overline{\text{STOP}}$: Start/Stop (1/0) channel.

$\overline{\text{B}}$/W: Byte/Word (0/1) transfers.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18). These pointers may be individually incremented or decremented after each transfer. If word transfers are performed the pointer is incremented or decremented by two. Each pointer may point into either memory or I/O space. Since the DMA channels can perform transfers to or from odd addresses, there is no restriction on values for the pointer registers. Higher transfer rates can be obtained if all word transfers are performed to even addresses, since this will allow data to be accessed in a single bus cycle.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). The register is decremented after every DMA cycle, regardless of the state of the TC bit in the DMA Control Register. If the TC bit in the DMA control word is set or if unsynchronized transfers are programmed, however, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). When destination synchronized transfers are performed, data will not be fetched from the source address until the destination device signals that it is ready to receive it. Also, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another destination synchronized DMA cycle will begin after two processor clocks. This allows the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. Table 14 shows the maximum DMA transfer rates.

Table 14. Maximum DMA Transfer Rates @ CLKOUT = 10 MHz

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	2.5MBytes/sec	2.5MBytes/sec
Source Synch.	2.5MBytes/sec	2.5MBytes/sec
Destination Synch.	1.7MBytes/sec	2.0MBytes/sec

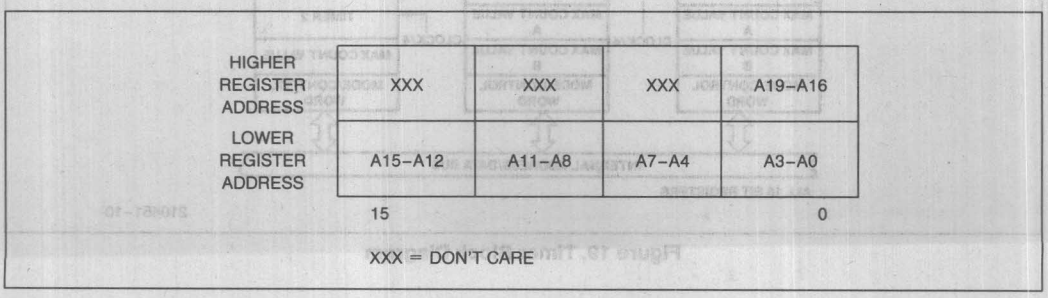


Figure 18. DMA Pointer Register Format

DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed to give one channel priority over the other, or they may be programmed to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses or word accesses to odd memory locations; also, an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/STOP bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also be generated. Therefore the source and destination transfer pointers, and the transfer count register (if used) must be programmed before the ST/STOP bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/NOCHG bit is cleared when the control register is written, the ST/STOP bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the DMA channels will perform the following actions:

- The Start/Stop bit for each channel will be reset to STOP.
- Any transfer in progress is aborted.

TIMERS

The 80186 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, the third timer can be used as a prescaler to the other two, or as a DMA request source.

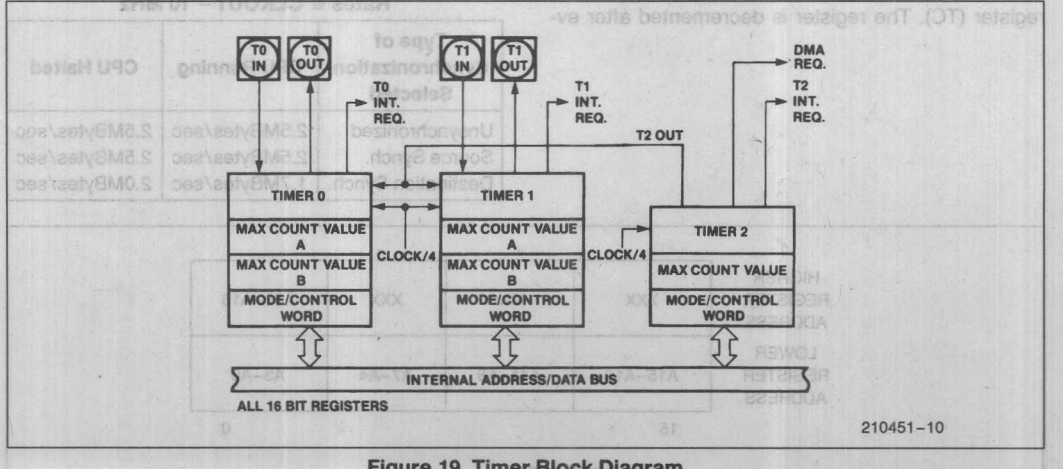


Figure 19. Timer Block Diagram

Timer Operation

The timers are controlled by 11 16-bit registers in the peripheral control block. The configuration of these registers is shown in Table 15. The count register contains the current value of the timer. It can be read or written at any time independent of whether the timer is running or not. The value of this register will be incremented for each timer event. Each of the timers is equipped with a MAX COUNT register, which defines the maximum count the timer will reach. After reaching the MAX COUNT register value, the timer count value will reset to zero during that same clock, i.e., the maximum count value is never stored in the count register itself. Timers 0 and 1 are, in addition, equipped with a second MAX COUNT register, which enables the timers to alternate their count between two different MAX COUNT values. If a single MAX COUNT register is used, the timer output pin will switch LOW for a single clock, 1 clock after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate (2 MHz for an 8 MHz CPU clock). Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input.

Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.
- Timers 0 and 1 can select between internal and external clocks, alternate between MAX COUNT registers and be set to retrigger on external events.
- The timers may be programmed to cause an interrupt on terminal count.

These options are selectable via the timer mode/control word.

Timer Mode/Control Register

The mode/control register (see Figure 20) allows the user to program the specific mode of operation or check the current programmed status for any of the three integrated timers.

Table 15. Timer Control Block Format

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

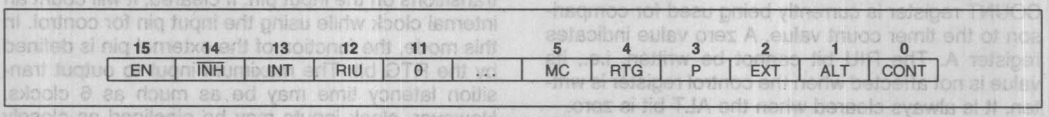


Figure 20. Timer Mode/Control Register

EN:

The enable bit provides programmer control over the timer's RUN/HALT status. When set, the timer is enabled to increment subject to the input pin constraints in the internal clock mode (discussed previously). When cleared, the timer will be inhibited from counting. All input pin transistions during the time EN is zero will be ignored. If CONT is zero, the EN bit is automatically cleared upon maximum count.

$\overline{\text{INH}}$:

The inhibit bit allows for selective updating of the enable (EN) bit. If INH is a one during the write to the mode/control word, then the state of the EN bit will be modified by the write. If INH is a zero during the write, the EN bit will be unaffected by the operation.This bit is not stored; it will always be a 0 on a read.

INT:

When set, the INT bit enables interrupts from the timer, which will be generated on every terminal count. If the timer is configured in dual MAX COUNT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller).

RIU:

The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

MC:

The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts.

Programmer intervention is required to clear this bit.

RTG:

Retrigger bit is only active for internal clocking (EXT = 0). In this case it determines the control function provided by the input pin.

If RTG = 0, the input level gates the internal clock on and off. If the input pin is HIGH, the timer will count; if the input pin is LOW, the timer will hold its value. As indicated previously, the input signal may be asynchronous with respect to the 80186 clock.

When RTG = 1, the input pin detects LOW-to-HIGH transitions. The first such transition starts the timer running, clearing the timer value to zero on the first clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

P:

The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

EXT:

The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80186 clock. If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

ALT:

The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse

outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT:

Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT = 1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The contents of this register may be read or written by the processor at any time. If the register is written while the timer is counting,the new value will take effect in the current count cycle.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached. A timer resets when the timer count register equals the max count value being used. If the timer count register or the max count register is changed so that the max count is less than the timer count, the timer does not immediately reset. Instead, the timer counts up to 0FFFFH, "wraps around" to zero, counts up to the max count value, and then resets.

Timers and Reset

Upon RESET, the Timers will perform the following actions:

- All EN (Enable) bits are reset preventing timer counting.
- For Timers 0 and 1, the RIU bits are reset to zero and the ALT bits are set to one. This results in the Timer Out pins going high.

INTERRUPT CONTROLLER

The 80186 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80186 interrupt controller has its own control register that sets the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service rountines for lower priority interrupts may be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The 80186 has a special Slave Mode in which the internal interrupt controller acts as a slave to an external master. The controller is programmed into this mode by setting bit 14 in the peripheral control block relocation register. (See Slave Mode section.)

MASTER MODE OPERATION

Interrupt Controller External Interface

Five pins are provided for external interrupt sources. One of these pins is NMI, the non-maskable interrupt. NMI is generally used for unusual events such as power-fail interrupts. The other four pins may be configured in any of the following ways:

- As four interrupt input lines with internally generated interrupt vectors.
- As an interrupt line and interrupt acknowledge line pair (Cascade Mode) with externally generated interrupt vectors plus two interrupt input lines with internally generated vectors.
- As two pairs of interrupt/interrupt acknowledge lines (Cascade Mode) with externally generated interrupt vectors.

External sources in the Cascade Mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80186 on the second cycle. The capability to interface to external 8259A programmable interrupt controllers is provided when the inputs are configured in Cascade Mode.

When in the fully nested mode four pins are used as direct interrupt requests as in Figure 22. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the in-service bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled, yet be suspended only by interrupts of higher priority than the in-service interrupt.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is executed at the end of the service routine

INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the Cascade Mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary Cascade Mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 8259As. Three levels of priority are created, requiring priority resolution in the 80186 interrupt controller, the master 8259As, and the slave 8259As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

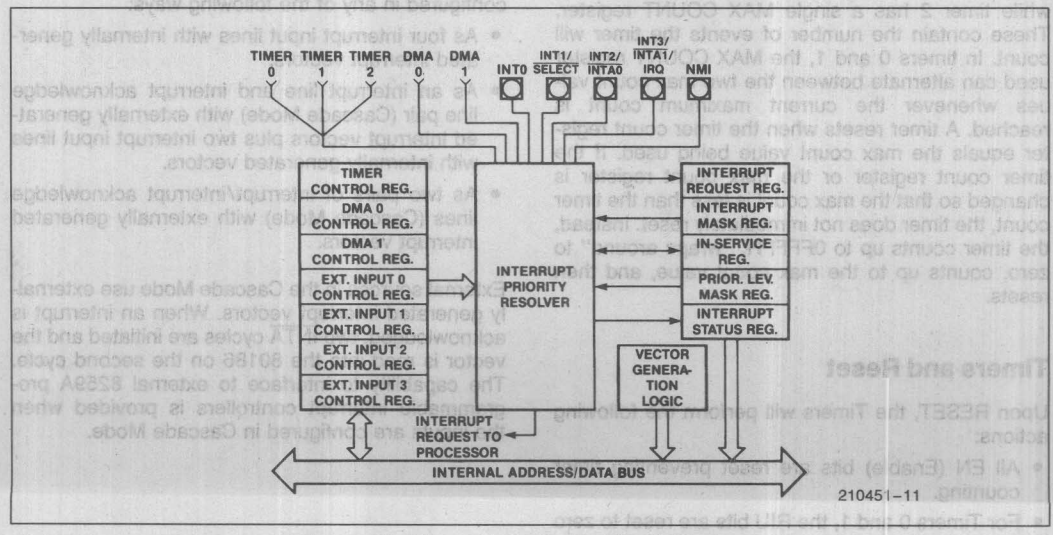


Figure 21. Interrupt Controller Block Diagram

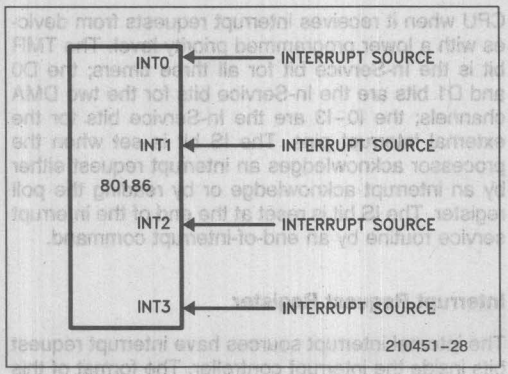


Figure 22. Fully Nested (Direct) Mode Interrupt Controller Connections

Special Fully Nested Mode

This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 8259A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80186 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80186 controller until the 80186 in-service bit is reset. In Special Fully Nested Mode, the 80186 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80186 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the IS register in the external master 8259A is required to determine if there is more than one bit set. If so, the IS bit in the 80186 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (*Figure 32*). *Bit 15 in the poll word* indicates to the processor that an interrupt of high enough priority is requesting service. Bits 0–4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80186 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

Master Mode Features

Programmable Priority

The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority). All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, other interrupt requests can be serviced.

End-of-Interrupt Command

The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

Trigger Mode

The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger

mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the 80186 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to re-enable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

Interrupt Vectoring

The 80186 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Mode. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 24. It contains 15 registers. All registers can both be read or written unless specified otherwise.

In-Service Register

This register can be read from or written into. The format is shown in Figure 25. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command.

Interrupt Request Register

The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 25. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits are set when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Writes to the interrupt request register will affect the D0 and D1 interrupt request bits. Setting either bit will cause the corresponding interrupt request while clearing either bit will remove the corresponding interrupt request. All other bits in the register are read-only.

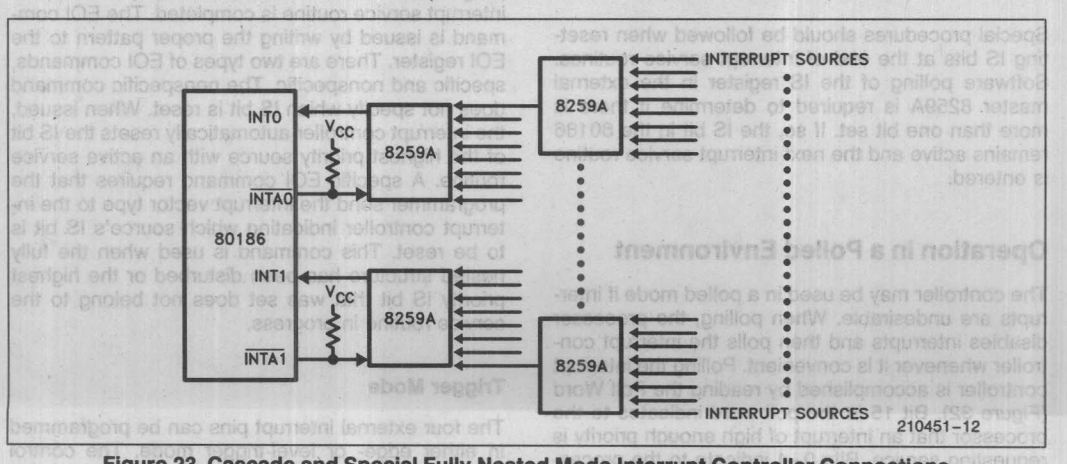


Figure 23. Cascade and Special Fully Nested Mode Interrupt Controller Connections

Mask Register

This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 25. A one in a bit position corresponding to a particular source masks the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

	OFFSET
INT3 CONTROL REGISTER	3EH
INT2 CONTROL REGISTER	3CH
INT1 CONTROL REGISTER	3AH
INT0 CONTROL REGISTER	38H
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	34H
TIMER CONTROL REGISTER	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY MASK REGISTER	2AH
MASK REGISTER	28H
POLL STATUS REGISTER	26H
POLL REGISTER	24H
EOI REGISTER	22H

Figure 24. Interrupt Controller Registers (Master Mode)

Priority Mask Register

This register masks all interrupts below a particular interrupt priority level. The format of this register is shown in Figure 26. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so no interrupts are masked due to priority number.

Interrupt Status Register

This register contains general interrupt controller status information. The format of this register is shown in Figure 27. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. This bit allows prompt service of all non-maskable interrupts. This bit may also be set by the programmer.

IRTx: These three bits represent the individual timer interrupt request bits. These bits differentiate between timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt request. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

15	14	•	•	•	10	9	8	7	6	5	4	3	2	1	0
0	0	•	•	•	0	0	0	I3	I2	I1	I0	D1	D0	0	TMR

Figure 25. In-Service, Interrupt Request, and Mask Register Formats

15	14	•	•	•	•	•	•	•	•	•	3	2	1	0
0	0	•	•	•	•	•	•	•	•	•	0	PRM2	PRM1	PRM0

Figure 26. Priority Mask Register Format

15	14	•	•	•	•	•	7	6	5	4	3	2	1	0
DHLT	0	•	•	•	•	•	0	0	0	0	0	IRT2	IRT1	IRT0

Figure 27. Interrupt Status Register Format (Master Mode)

Timer, DMA 0, 1; Control Register

These registers are the control words for all the internal interrupt sources. The format for these registers is shown in Figure 28. The three bit positions PR0, PR1, and PR2 represent the programmable priority level of the interrupt source. The MSK bit inhibits interrupt requests from the interrupt source. The MSK bits in the individual control registers are the exact same bits as are in the Mask Register; modifying them in the individual control registers will also modify them in the Mask Register, and vice versa.

INT0-INT3 Control Registers

These registers are the control words for the four external input pins. Figure 29 shows the format of the INT0 and INT1 Control registers; Figure 30 shows the format of the INT2 and INT3 Control registers. In Cascade Mode or Special Fully Nested Mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest Priority = 000, Lowest Priority = 111

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this level is preceded by an inactive-to-active transition on the line. In both cases, the level must remain active until the interrupt is acknowledged.

MSK: Mask bit, 1 = mask; 0 = non-mask.

C: Cascade mode bit, 1 = cascade; 0 = direct

SFNM: Special Fully Nested Mode bit, 1 = SFNM

EOI Register

The end of the interrupt register is a command register which can only be written into. The format of this register is shown in Figure 31. It initiates an EOI command when written to by the 80186 CPU.

The bits in the EOI register are encoded as follows:

S_X: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10.

NOTE:

To reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

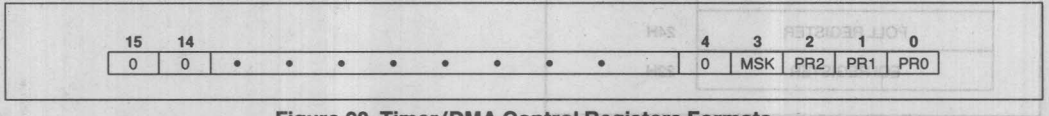


Figure 28. Timer/DMA Control Registers Formats

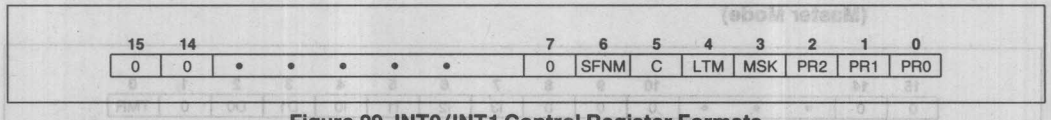


Figure 29. INT0/INT1 Control Register Formats

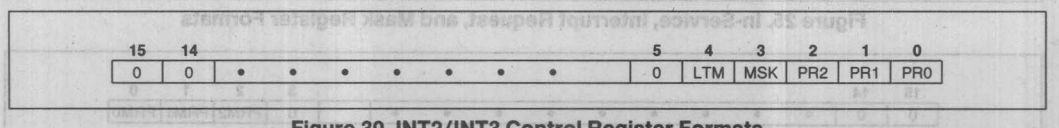


Figure 30. INT2/INT3 Control Register Formats

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

Poll and Poll Status Registers

These registers contain polling information. The format of these registers is shown in Figure 32. They can only be read. Reading the Poll register constitutes a software poll. This will set the IS bit of the highest priority pending interrupt. Reading the poll status register will not set the IS bit of the highest priority pending interrupt; only the status of pending interrupts will be provided.

Encoding of the Poll and Poll Status register bits are as follows:

S_X: Encoded information that indicates the vector type of the highest priority interrupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

SLAVE MODE OPERATION

When Slave Mode is used, the internal 80186 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80186 resources will be monitored by the internal interrupt controller, while the external controller functions as the system master interrupt controller. Upon reset, the 80186 will be in Master Mode. To provide for slave mode operation bit 14 of the relocation register should be set.

Because of pin limitations caused by the need to interface to an external 8259A master, the internal interrupt controller will no longer accept external inputs. There are however, enough 80186 interrupt controller inputs (internally) to dedicate one to each timer. In this mode, each timer interrupt source has its own mask bit, IS bit, and control word.

In Slave Mode each peripheral must be assigned a unique priority to ensure proper interrupt controller operation. Therefore, it is the programmer's responsibility to assign correct priorities and initialize interrupt control registers before enabling interrupts.

These level assignments must remain fixed in the Slave Mode of operation.

Slave Mode External Interface

The configuration of the 80186 with respect to an external 8259A master is shown in Figure 33. The INT0 (pin 45) input is used as the 80186 CPU interrupt input. IRQ (pin 41) functions as an output to send the 80186 slave-interrupt-request to one of the 8 master-PIC-inputs.

15	14	13								5	4	3	2	1	0
SPEC/ NSPEC	0	0	•	•	•	•	•	•	•	0	S4	S3	S2	S1	S0

Figure 31. EOI Register Format

15	14	13								5	4	3	2	1	0
INT REQ	0	0	•	•	•	•	•	•	•	0	S4	S3	S2	S1	S0

Figure 32. Poll and Poll Status Register Format

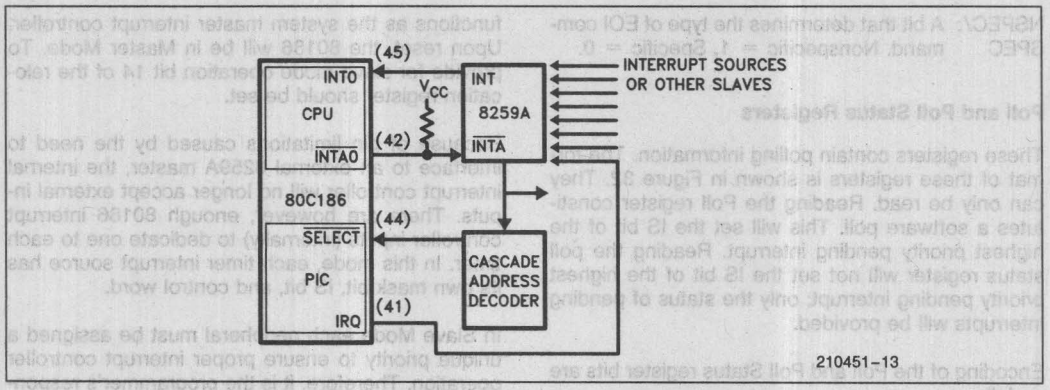


Figure 33. Slave Mode Interrupt Controller Connections

Correct master-slave interface requires decoding of the slave addresses (CAS0-2). Slave 8259As do this internally. Because of pin limitations, the 80186 slave address will have to be decoded externally. $\overline{\text{SELECT}}$ (pin 44) is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{\text{INTA0}}$ (pin 42) is used as an acknowledge output, suitable to drive the $\overline{\text{INTA}}$ input of an 8259A.

Interrupt Nesting

Slave Mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the Slave Mode

Vector generation in Slave Mode is exactly like that of an 8259A or 82C59A slave. The interrupt controller generates an 8-bit vector type number which the CPU multiplies by four to use as an address into the vector table. The five most significant bits of this type number are user-programmable while the three least significant bits are defined according to Figure 34. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In Slave Mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the Slave Mode

All control and command registers are located inside the internal peripheral control block. Figure 34 shows the offsets of these registers.

End-of-Interrupt Register

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 35. It initiates an EOI command when written by the 80186 CPU.

The bits in the EOI register are encoded as follows:

VT_X: Three least-significant vector type bits corresponding to the source for which the IS bit is to be reset. Figure 34 indicates these bits.

In-Service Register

This register can be read from or written into. It contains the in-service bit for each of the internal interrupt sources. The format for this register is shown in Figure 36. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

Interrupt Request Register

This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 36. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request. As in Master Mode, D0 and D1 are read/write; all other bits are read only.

Mask Register

This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 36. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

Control Registers

These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 37. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source.

msk: mask bit for the priority level indicated by pr_x bits.

	OFFSET
TIMER2 CONTROL REGISTER (VECTOR TYPE xxxxx101)	3AH
TIMER1 CONTROL REGISTER (VECTOR TYPE xxxxx100)	38H
DMA1 CONTROL REGISTER (VECTOR TYPE xxxxx011)	36H
DMA0 CONTROL REGISTER (VECTOR TYPE xxxxx010)	34H
TIMER0 CONTROL REGISTER (VECTOR TYPE xxxxx000)	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT-REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY-LEVEL MASK REGISTER	2AH
MASK REGISTER	28H
SPECIFIC EOI REGISTER	22H
INTERRUPT VECTOR REGISTER	20H

Figure 34. Interrupt Controller Registers (Slave Mode)

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	0	0	0	VT2	VT1	VT0

Figure 35. Specific EOI Register Format

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	TMR2	TMR1	D1	D0	0	TMR0

Figure 36. In-Service, Interrupt Request, and Mask Register Format

This register indicates the lowest priority-level interrupt which will be serviced.

The encoding of the bits in this register is:

m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

Interrupt Status Register

This register is defined as in Master Mode except that DHLT is not implemented. (See Figure 27).

- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-Cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to Master Mode.

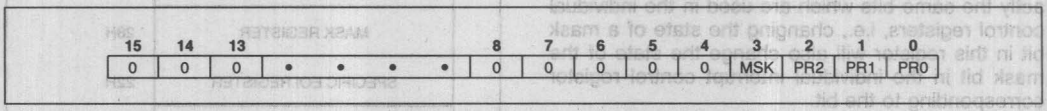


Figure 37. Control Word Format

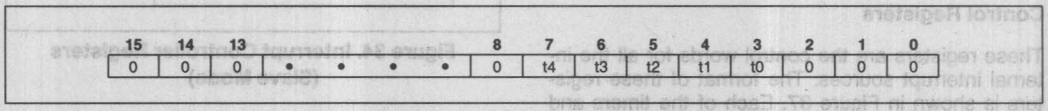


Figure 38. Interrupt Vector Register Format

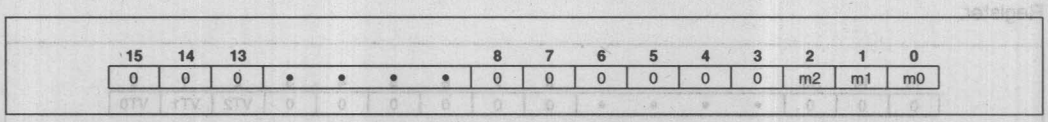


Figure 39. Priority Level Mask Register

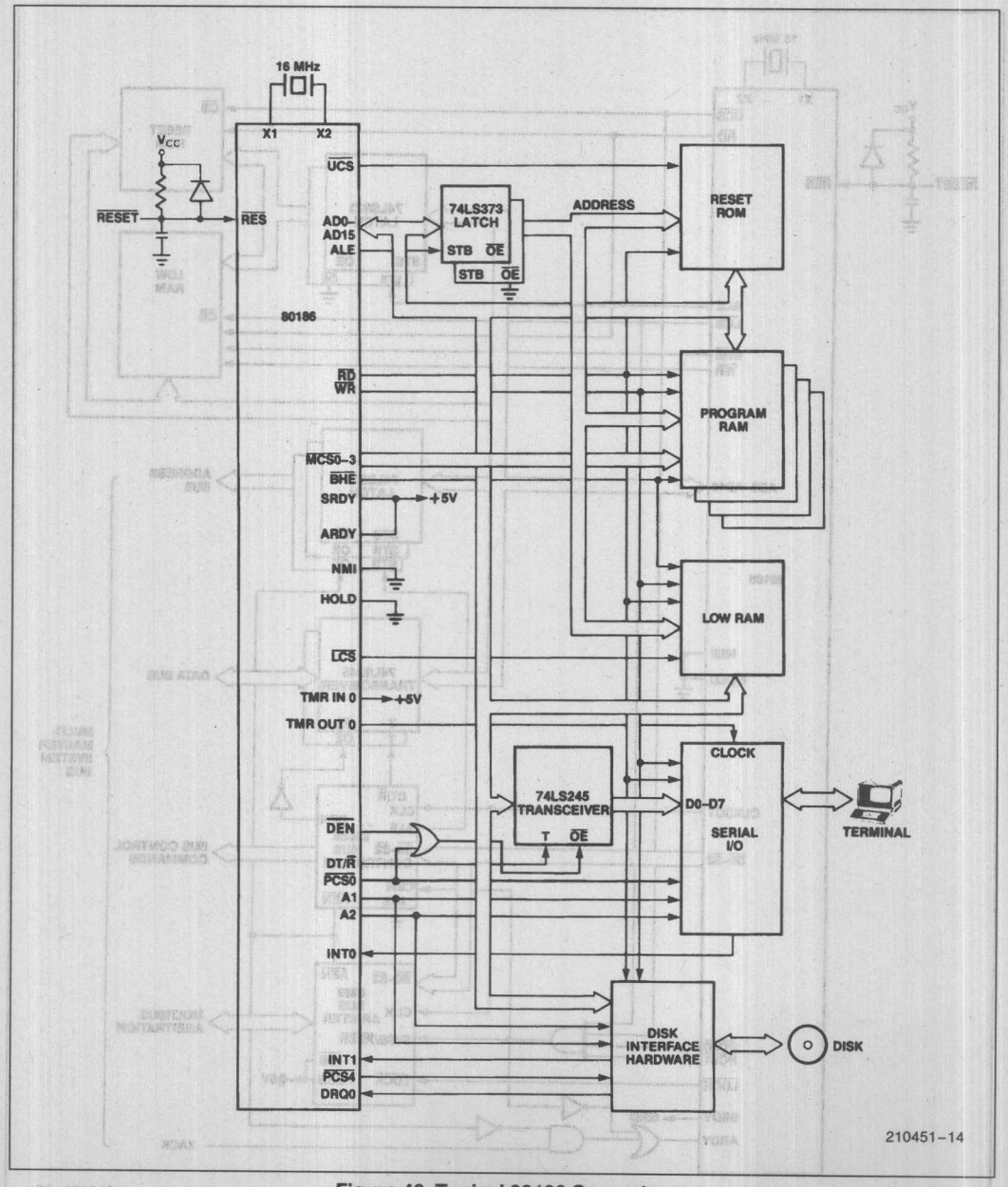


Figure 40. Typical 80186 Computer

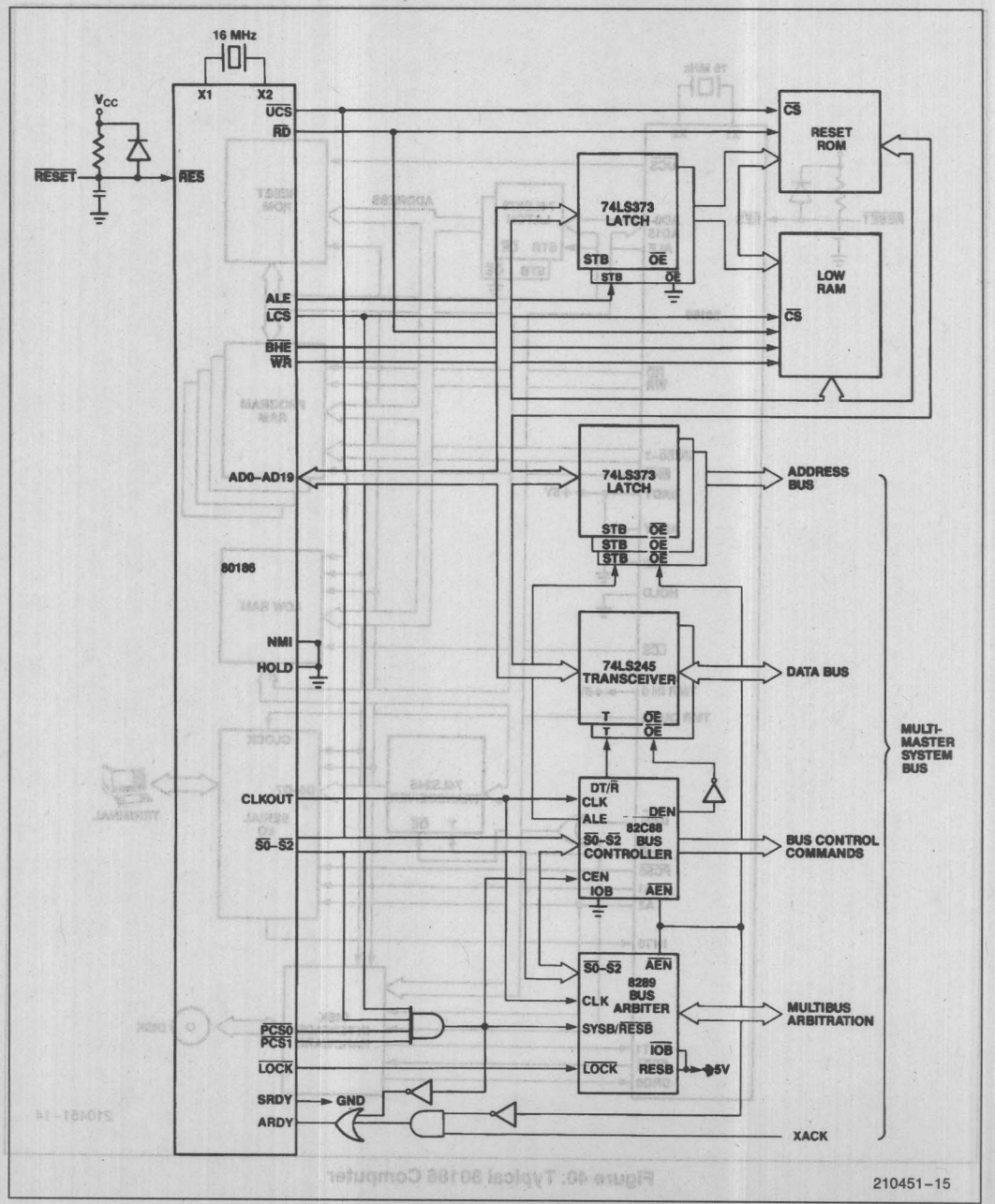


Figure 41. Typical 80186 Multi-Master Bus Interface

V_{IH}	Input High Voltage (All except X1 and $\overline{RES}$)	2.0	V_{CC} + 0.5	V	
V_{IH1}	Input High Voltage ($\overline{RES}$)	3.0	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_a = 2.5 mA for $\overline{S0}$–$\overline{S2}$ I_a = 2.0 mA for all other Outputs
V_{OH}	Output High Voltage	2.4		V	I_{oa} = −400 μA
I_{CC}	Power Supply Current		600*	mA	T_A = −40°C
			550	mA	T_A = 0°C
			415	mA	T_A = +70°C
I_{LI}	Input Leakage Current		±10	μA	0V < V_{IN} < V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V < V_{OUT} < V_{CC}
V_{CLO}	Clock Output Low		0.6	V	I_a = 4.0 mA
V_{CHO}	Clock Output High	4.0		V	I_{oa} = −200 μA
V_{CLI}	Clock Input Low Voltage	−0.5	0.6	V	
V_{CHI}	Clock Input High Voltage	3.9	V_{CC} + 1.0	V	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	

*For extended temperature parts only.

PIN TIMINGS

A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = 5V ±10%)

80186 Timing Requirements All Timings Measured At 1.5V Unless Otherwise Noted.

Symbol	Parameter	80186 (8 MHz)		80186-10 (10 MHz)		Units	Test Conditions
		Min	Max	Min	Max		
T_{DVCL}	Data in Setup (A/D)	20		15		ns	
T_{CLDX}	Data in Hold (A/D)	10		8		ns	
T_{ARYHCH}	Asynchronous Ready (ARDY) Active Setup Time (1)	20		15		ns	
T_{ARYLCL}	ARDY Inactive Setup Time	35		25		ns	
T_{CLARX}	ARDY Hold Time	15		15		ns	
T_{ARYCHL}	Asynchronous Ready Inactive Hold Time	15		15		ns	
T_{SRYCL}	Synchronous Ready (SRDY) Transition Setup Time (2)	20		20		ns	
T_{CLSRY}	SRDY Transition Hold Time (2)	15		15		ns	
T_{HVCL}	HOLD Setup (1)	25		20		ns	
T_{INVCH}	INTR, NMI, $\overline{TEST}$, TIM IN, Setup (1)	25		25		ns	
T_{INVCL}	DRQ0, DRQ1, Setup (1)	25		20		ns	
80186 Master Interface Timing Responses							
T_{CLAV}	Address Valid Delay	5	55	5	44	ns	C_L = 20–200 pF all Outputs (Except T_{CLTMV}) @ 8 & 10 MHz
T_{CLAX}	Address Hold	10		10		ns	
T_{CLAZ}	Address Float Delay	T_{CLAX}	35	T_{CLAX}	30	ns	
T_{CHCZ}	Command Lines Float Delay		45		40	ns	
T_{CHCV}	Command Lines Valid Delay (after Float)		55		45	ns	
T_{LHLL}	ALE Width	$T_{CLCL}-35$		$T_{CLCL}-30$		ns	
T_{CHLH}	ALE Active Delay		35		30	ns	
T_{CHLL}	ALE Inactive Delay		35		30	ns	
T_{LLAX}	Address Hold from ALE Inactive	$T_{CHCL}-25$		$T_{CHCL}-20$		ns	
T_{CLDV}	Data Valid Delay	10	44	10	40	ns	
T_{CLDOX}	Data Hold Time	10		10		ns	
T_{WHDX}	Data Hold after WR	$T_{CLCL}-40$		$T_{CLCL}-34$		ns	
T_{CVCTV}	Control Active Delay 1	5	50	5	40	ns	
T_{CHCTV}	Control Active Delay 2	10	55	10	44	ns	
T_{CVCTX}	Control Inactive Delay	5	55	5	44	ns	
T_{CVDEX}	$\overline{DEN}$ Inactive Delay (Non-Write Cycle)	10	70	10	56	ns	

1. To guarantee recognition at next clock.
2. To guarantee proper operation.

PIN TIMINGS (Continued)

A.C. CHARACTERISTICS ($T_A = 0°C$ to $+70°C$, $V_{CC} = 5V \pm 10\%$) (Continued)

80186 Master Interface Timing Responses (Continued)

Symbol	Parameter	80186 (8 MHz)		80186-10 (10 MHz)		Units	Test Conditions
		Min	Max	Min	Max		
T_{AZRL}	Address Float to $\overline{RD}$ Active	0		0		ns	
T_{CLRL}	$\overline{RD}$ Active Delay	10	70	10	56	ns	
T_{CLRH}	$\overline{RD}$ Inactive Delay	10	55	10	44	ns	
T_{RHAV}	$\overline{RD}$ Inactive to Address Active	$T_{CLCL}-40$		$T_{CLCL}-40$		ns	
T_{CLHAV}	HLDA Valid Delay	5	50	5	40	ns	
T_{RLRH}	$\overline{RD}$ Width	$2T_{CLCL}-50$		$2T_{CLCL}-46$		ns	
T_{WLWH}	$\overline{WR}$ Width	$2T_{CLCL}-40$		$2T_{CLCL}-34$		ns	
T_{AVLL}	Address Valid to ALE Low	$T_{CLCH}-25$		$T_{CLCH}-19$		ns	
T_{CHSV}	Status Active Delay	10	55	10	45	ns	
T_{CLSH}	Status Inactive Delay	10	65	10	50	ns	
T_{CLTMV}	Timer Output Delay		60		48	ns	100 pF max @ 8 & 10 MHz
T_{CLRO}	Reset Delay		60		48	ns	
T_{CHQSV}	Queue Status Delay		35		28	ns	
T_{CHDX}	Status Hold Time	10		10		ns	
T_{AVCH}	Address Valid to Clock High	10		10		ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	5	65	5	60	ns	
80186 Chip-Select Timing Responses							
T_{CLCSV}	Chip-Select Active Delay		66		45	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	35		35		ns	
T_{CHCSX}	Chip-Select Inactive Delay	5	35	5	32	ns	
80186 CLKIN Requirements							
T_{CKIN}	CLKIN Period	62.5	250	50	250	ns	
T_{CKHL}	CLKIN Fall Time		10		10	ns	3.5 to 1.0V
T_{CKLH}	CLKIN Rise Time		10		10	ns	1.0 to 3.5V
T_{CLCK}	CLKIN Low Time	25		20		ns	1.5V
T_{CHCK}	CLKIN High Time	25		20		ns	1.5V
80186 CLKOUT Timing (200 pF load)							
T_{CICO}	CLKIN to CLKOUT Skew		50		25	ns	
T_{CLCL}	CLKOUT Period	125	500	100	500	ns	
T_{CLCH}	CLKOUT Low Time	$\frac{1}{2} T_{CLCL}-7.5$		$\frac{1}{2} T_{CLCL}-6.0$		ns	1.5V
T_{CHCL}	CLKOUT High Time	$\frac{1}{2} T_{CLCL}-7.5$		$\frac{1}{2} T_{CLCL}-6.0$		ns	1.5V
T_{CH1CH2}	CLKOUT Rise Time		15		12	ns	1.0 to 3.5V
T_{CL2CL1}	CLKOUT Fall Time		15		12	ns	3.5 to 1.0V

EXPLANATION OF THE AC SYMBOLS

Each timing symbol has from 5 to 7 characters. The first character is always a "T" (stands for time). The other characters, depending on their positions, stand for the name of a signal or the logical status of that signal. The following is a list of all the characters and what they stand for.

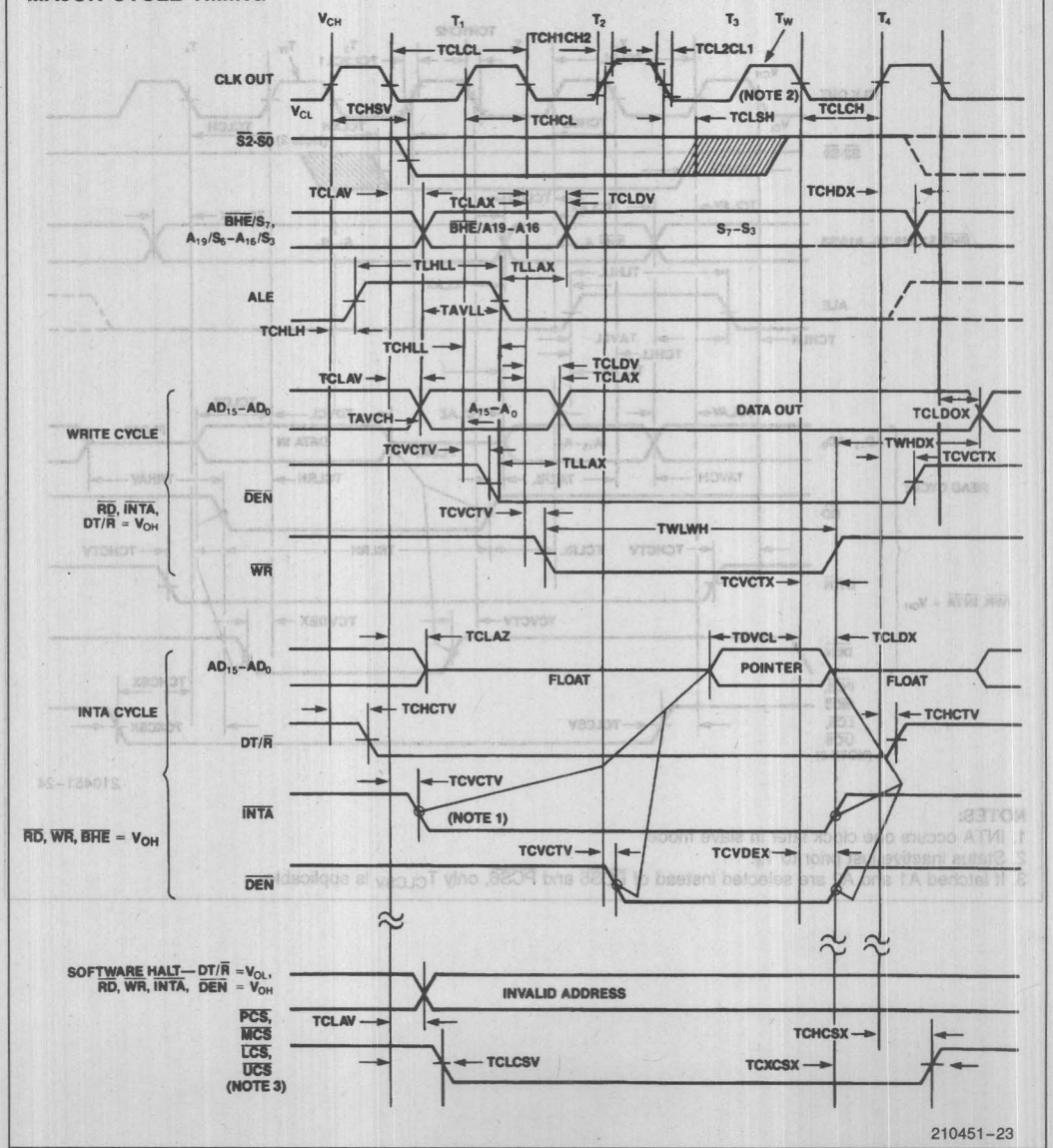
A: Address
ARY: Asynchronous Ready Input
C: Clock Output
CK: Clock Input
CS: Chip Select
CT: Control (DT/$\overline{R}$, $\overline{DEN}$, . . .)
D: Data Input
DE: $\overline{DEN}$
H: Logic Level High
IN: Input (DRQ0, TIM0, . . .)
L: Logic Level Low or ALE
O: Output
QS: Queue Status (QS1, QS2)
R: $\overline{RD}$ signal, RESET signal
S: Status ($\overline{S0}$, $\overline{S1}$, $\overline{S2}$)
SRY: Synchronous Ready Input
V: Valid
W: WR Signal
X: No Longer a Valid Logic Level
Z: Float

Examples:

T_{CLAV} — Time from Clock low to Address valid
T_{CHLH} — Time from Clock high to ALE high
T_{CLCSV} — Time from Clock low to Chip Select valid

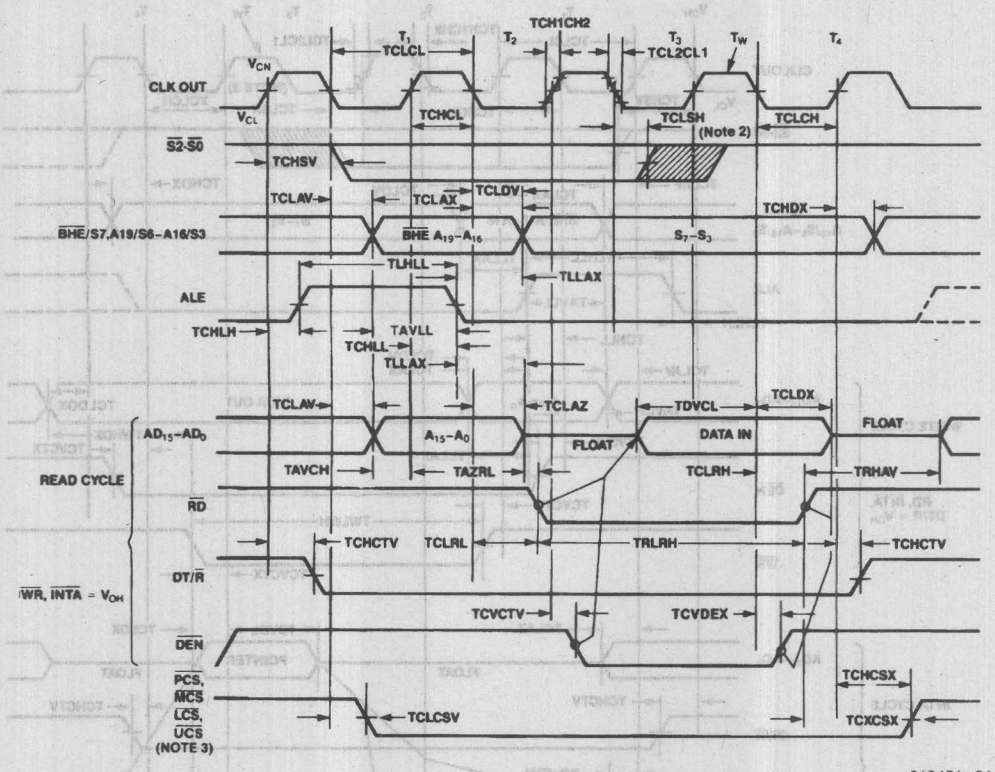
WAVEFORMS

MAJOR CYCLE TIMING



WAVEFORMS (Continued)

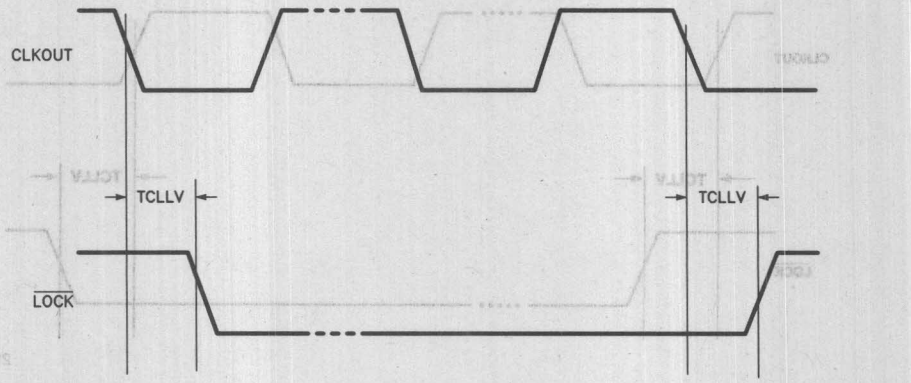
MAJOR CYCLE TIMING (Continued)



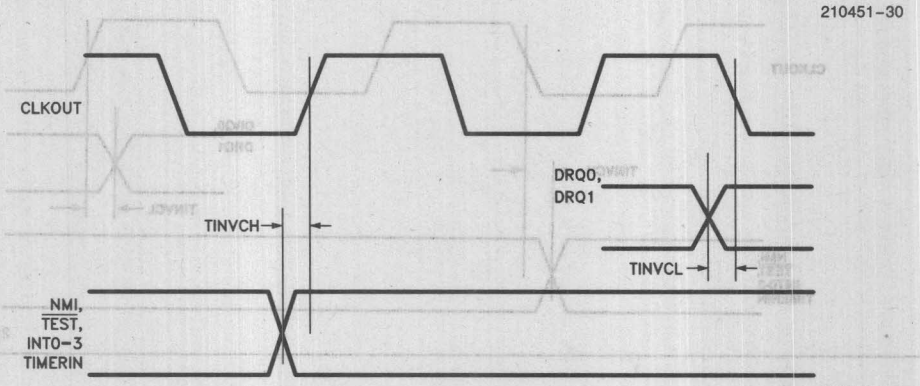
210451-24

NOTES:
1. INTA occurs one clock later in slave mode.
2. Status inactive just prior to T_4.
3. If latched A1 and A2 are selected instead of $\overline{PCS5}$ and $\overline{PCS6}$, only T_{CLCSV} is applicable.

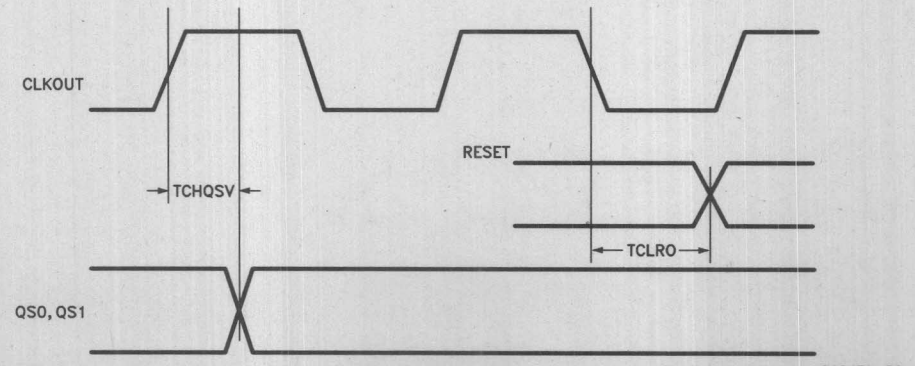
WAVEFORMS (Continued)



210451-30

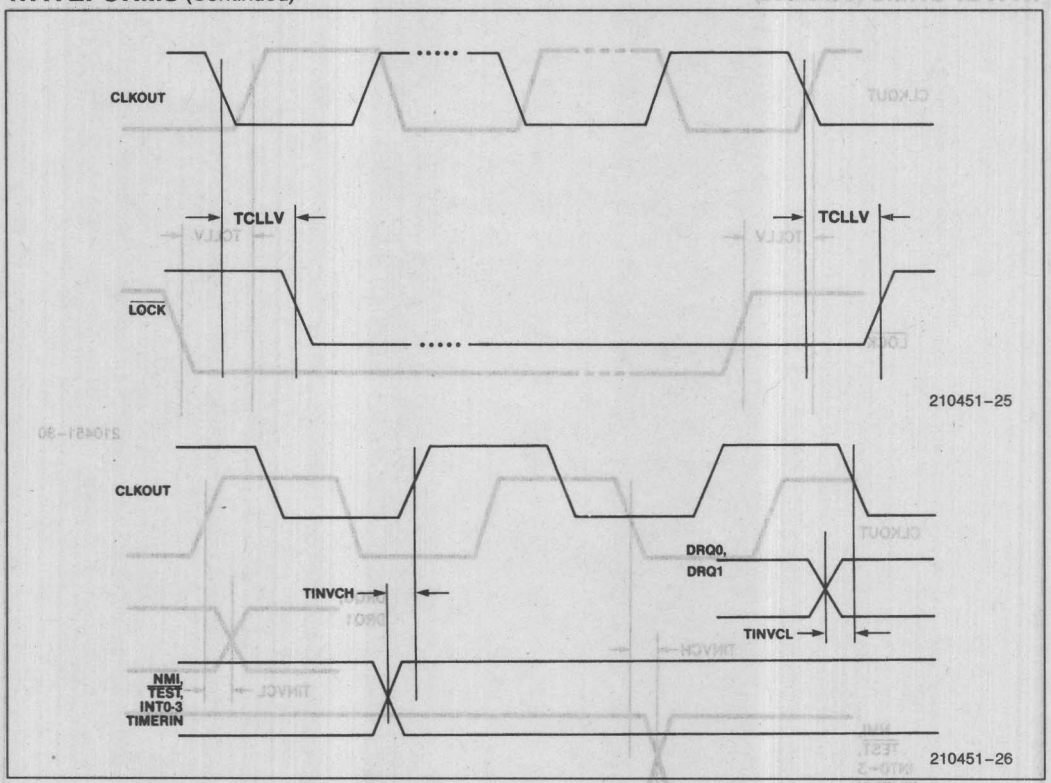


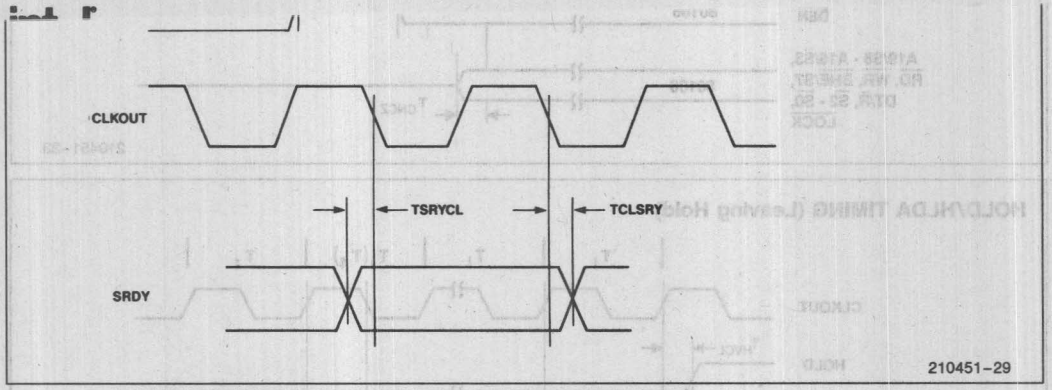
210451-31



210451-32

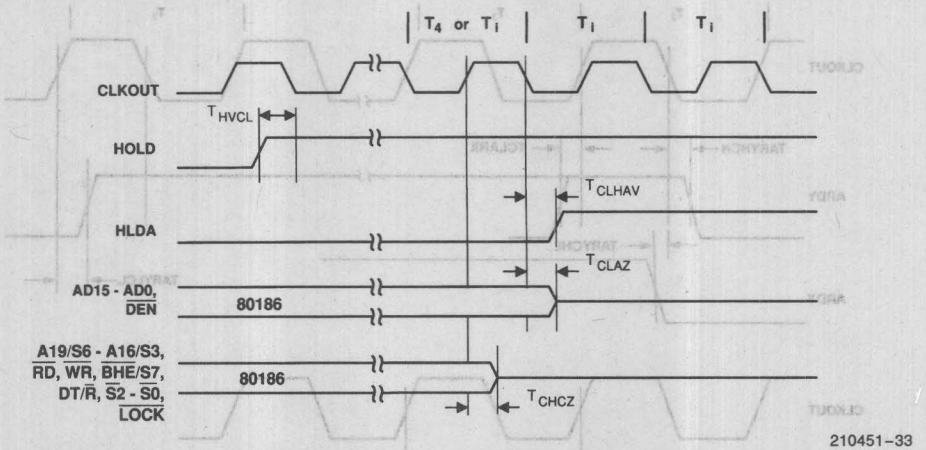
WAVEFORMS (Continued)




CLKOUT
TSRYCL
TCLSRY
SRDY
210451-29

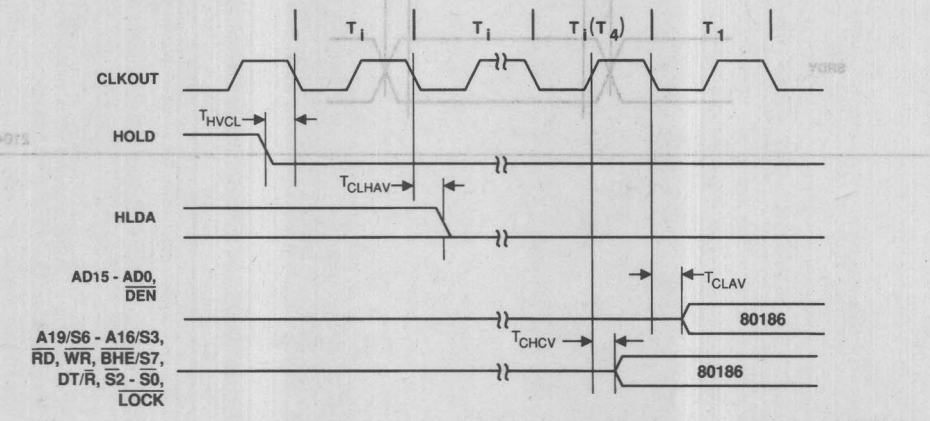
WAVEFORMS (Continued)

HOLD/HLDA TIMING (Entering Hold)



210451-33

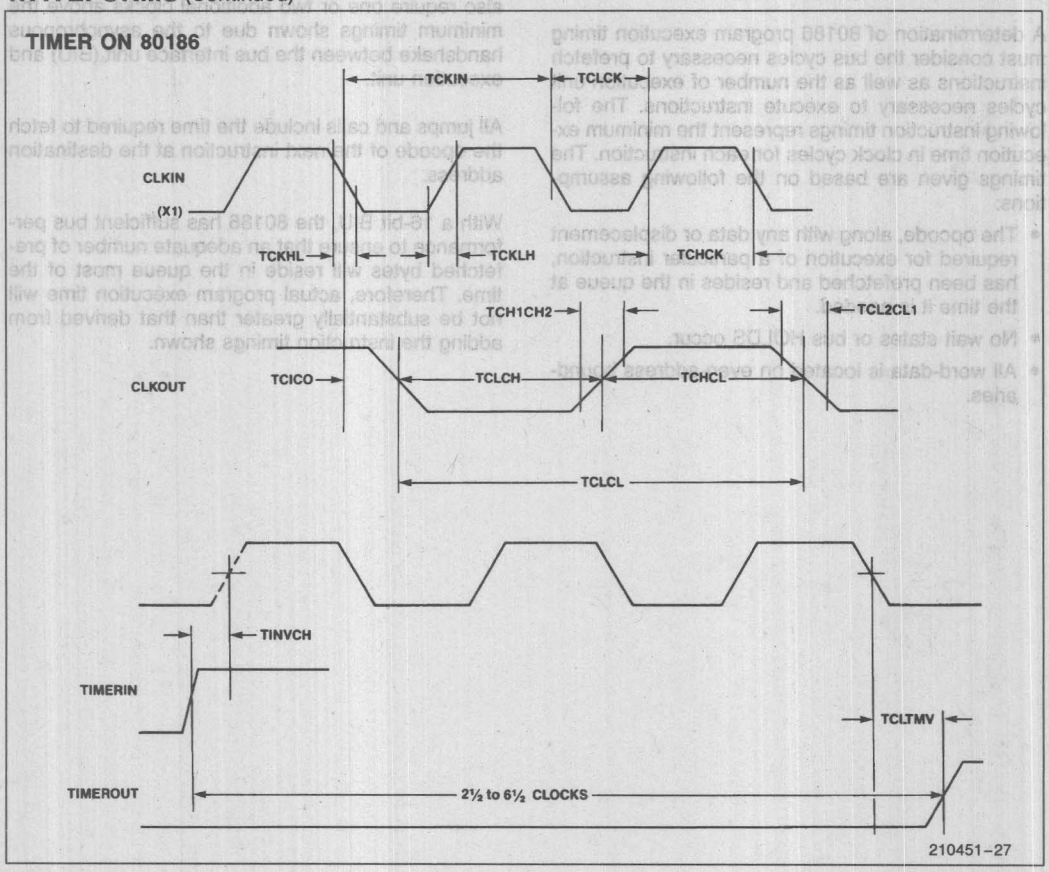
HOLD/HLDA TIMING (Leaving Hold)



210451-34

WAVEFORMS (Continued)

TIMER ON 80186



80186 EXPRESS

The Intel EXPRESS system offers enhancements to the operational specifications of the 80186 microprocessor. EXPRESS products are designed to meet the needs of those applications whose operating requirements exceed commercial standards.

The EXPRESS program includes the commercial standard temperature range with burn-in and an extended temperature range without burn-in.

With the commercial standard temperature range operational characteristics are guaranteed over the temperature range of 0°C to +70°C. With the extended temperature range option, operational characteristics are guaranteed over the range of −40°C to +85°C.

The optional burn-in is dynamic, for a minimum time of 160 hours at +125°C with V_{CC} = 5.5V ±0.25V, following guidelines in MIL-STD-883, Method 1015.

Package types and EXPRESS versions are identified by a one- or two-letter prefix to the part number. The prefixes are listed in Table 16. All A.C. and D.C. specifications not mentioned in this section are the same for both commercial and EXPRESS parts.

Table 16. Prefix Identification

Prefix	Package Type	Temperature Range	Burn-In
A	PGA	Commercial	No
N	PLCC	Commercial	No
R	LCC	Commercial	No
TA	PGA	Extended	No
QA	PGA	Commercial	Yes
QR	LCC	Commercial	Yes

NOTE:
Not all package/temperature range/speed combinations are available.

80186 EXECUTION TIMINGS

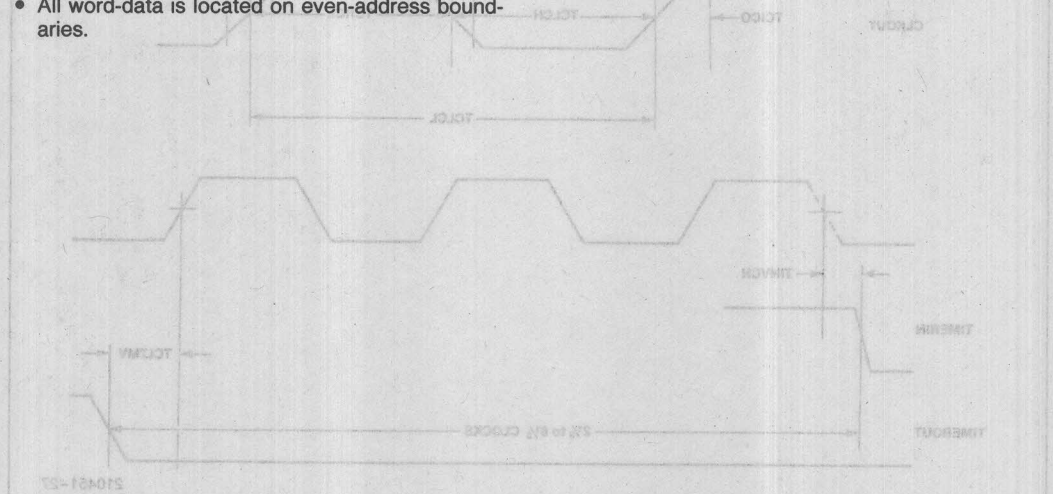
A determination of 80186 program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDS occur.
- All word-data is located on even-address boundaries.

All instructions which involve memory accesses can also require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the bus interface unit (BIU) and execution unit.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

With a 16-bit BIU, the 80186 has sufficient bus performance to ensure that an adequate number of prefetched bytes will reside in the queue most of the time. Therefore, actual program execution time will not be substantially greater than that derived from adding the instruction timings shown.



INSTRUCTION SET SUMMARY

Function	Format				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1000100w	mod reg r/m			2/12	
Register/memory to register	1000101w	mod reg r/m			2/9	
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1	12–13	8/16-bit
Immediate to register	1011w reg	data	data if w=1		3–4	8/16-bit
Memory to accumulator	1010000w	addr-low	addr-high		8	
Accumulator to memory	1010001w	addr-low	addr-high		9	
Register/memory to segment register	10001110	mod 0 reg r/m			2/9	
Segment register to register/memory	10001100	mod 0 reg r/m			2/11	
PUSH = Push:						
Memory	11111111	mod 110 r/m			16	
Register	01010 reg				10	
Segment register	000reg110				9	
Immediate	011010s0	data	data if s=0		10	
PUSHA = Push All	01100000				36	
POP = Pop:						
Memory	10001111	mod 000 r/m			20	
Register	01011 reg				10	
Segment register	000reg111	(reg≠01)			8	
POPA = Pop All	01100001				51	
XCHG = Exchange:						
Register/memory with register	1000011w	mod reg r/m			4/17	
Register with accumulator	10010 reg				3	
IN = Input from:						
Fixed port	1110010w	port			10	
Variable port	1110110w				8	
OUT = Output to:						
Fixed port	1110011w	port			9	
Variable port	1110111w				7	
XLAT = Translate byte to AL	11010111				11	
LEA = Load EA to register	10001101	mod reg r/m			6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)		18	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)		18	
LAHF = Load AH with flags	10011111				2	
SAHF = Store AH into flags	10011110				3	
PUSHF = Push flags	10011100				9	
POPF = Pop flags	10011101				8	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
DATA TRANSFER (Continued)			
SEGMENT = Segment Override:			
CS	00101110	2	
SS	00110110	2	
DS	00111110	2	
ES	00100110	2	
ARITHMETIC			
ADD = Add:			
Reg/memory with register to either	000000dw | mod reg r/m	3/10	
Immediate to register/memory	100000sw | mod 000 r/m | data | data if s w=01	4/16	
Immediate to accumulator	0000010w | data | data if w=1	3/4	8/16-bit
ADC = Add with carry:			
Reg/memory with register to either	000100dw | mod reg r/m	3/10	
Immediate to register/memory	100000sw | mod 010 r/m | data | data if s w=01	4/16	
Immediate to accumulator	0001010w | data | data if w=1	3/4	8/16-bit
INC = Increment:			
Register/memory	1111111w | mod 000 r/m	3/15	
Register	01000 reg	3	
SUB = Subtract:			
Reg/memory and register to either	001010dw | mod reg r/m	3/10	
Immediate from register/memory	100000sw | mod 101 r/m | data | data if s w=01	4/16	
Immediate from accumulator	0010110w | data | data if w=1	3/4	8/16-bit
SBB = Subtract with borrow:			
Reg/memory and register to either	000110dw | mod reg r/m	3/10	
Immediate from register/memory	100000sw | mod 011 r/m | data | data if s w=01	4/16	
Immediate from accumulator	0001110w | data | data if w=1	3/4	8/16-bit
DEC = Decrement			
Register/memory	1111111w | mod 001 r/m	3/15	
Register	01001 reg	3	
CMP = Compare:			
Register/memory with register	0011101w | mod reg r/m	3/10	
Register with register/memory	0011100w | mod reg r/m	3/10	
Immediate with register/memory	100000sw | mod 111 r/m | data | data if s w=01	3/10	
Immediate with accumulator	0011110w | data | data if w=1	3/4	8/16-bit
NEG = Change sign register/memory	1111011w | mod 011 r/m	3/10	
AAA = ASCII adjust for add	00110111	8	
DAA = Decimal adjust for add	00100111	4	
AAS = ASCII adjust for subtract	00111111	7	
DAS = Decimal adjust for subtract	00101111	4	
MUL = Multiply (unsigned):	1111011w | mod 100 r/m		
Register-Byte		26–28	
Register-Word		35–37	
Memory-Byte		32–34	
Memory-Word		41–43	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
ARITHMETIC (Continued)			
IMUL = Integer multiply (signed):	1 1 1 1 0 1 1 w | mod 1 0 1 r/m		
Register-Byte		25–28	
Register-Word		34–37	
Memory-Byte		31–34	
Memory-Word		40–43	
IMUL = Integer Immediate multiply (signed)	0 1 1 0 1 0 s 1 | mod reg r/m | data | data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1 1 1 1 0 1 1 w | mod 1 1 0 r/m		
Register-Byte		29	
Register-Word		38	
Memory-Byte		35	
Memory-Word		44	
IDIV = Integer divide (signed):	1 1 1 1 0 1 1 w | mod 1 1 1 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67	
AAM = ASCII adjust for multiply	1 1 0 1 0 1 0 0 | 0 0 0 0 1 0 1 0	19	
AAD = ASCII adjust for divide	1 1 0 1 0 1 0 1 | 0 0 0 0 1 0 1 0	15	
CBW = Convert byte to word	1 0 0 1 1 0 0 0	2	
CWD = Convert word to double word	1 0 0 1 1 0 0 1	4	
LOGIC			
Shift/Rotate Instructions:			
Register/Memory by 1	1 1 0 1 0 0 0 w | mod TTT r/m	2/15	
Register/Memory by CL	1 1 0 1 0 0 1 w | mod TTT r/m	5+n/17+n	
Register/Memory by Count	1 1 0 0 0 0 0 w | mod TTT r/m | count	5+n/17+n	
TTT Instruction 0 0 0 ROL 0 0 1 ROR 0 1 0 RCL 0 1 1 RCR 1 0 0 SHL/SAL 1 0 1 SHR 1 1 1 SAR			
AND = **And:**			
Reg/memory and register to either	0 0 1 0 0 0 d w | mod reg r/m	3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 0 0 r/m | data | data if w=1	4/16	
Immediate to accumulator	0 0 1 0 0 1 0 w | data | data if w=1	3/4	8/16-bit
TEST = **And function to flags, no result:**			
Register/memory and register	1 0 0 0 0 1 0 w | mod reg r/m	3/10	
Immediate data and register/memory	1 1 1 1 0 1 1 w | mod 0 0 0 r/m | data | data if w=1	4/10	
Immediate data and accumulator	1 0 1 0 1 0 0 w | data | data if w=1	3/4	8/16-bit
OR = **Or:**			
Reg/memory and register to either	0 0 0 0 1 0 d w | mod reg r/m	3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 0 0 1 r/m | data | data if w=1	4/16	
Immediate to accumulator	0 0 0 0 1 1 0 w | data | data if w=1	3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
LOGIC (Continued)						
XOR = Exclusive or:						
Reg/memory and register to either	001100dw	mod reg r/m			3/10	
Immediate to register/memory	1000000w	mod 110 r/m	data	data if w=1	4/16	
Immediate to accumulator	0011010w	data	data if w=1		3/4	8/16-bit
NOT = Invert register/memory	1111011w	mod 010 r/m			3/10	
STRING MANIPULATION						
MOVS = Move byte/word	1010010w				14	
CMPS = Compare byte/word	1010011w				22	
SCAS = Scan byte/word	1010111w				15	
LODS = Load byte/wd to AL/AX	1010110w				12	
STOS = Store byte/wd from AL/AX	1010101w				10	
INS = Input byte/wd from DX port	0110110w				14	
OUTS = Output byte/wd to DX port	0110111w				14	
Repeated by count in CX (REP/REPE/REPZ/REPNE/REPNZ)						
MOVS = Move string	11110010	1010010w			8+8n	
CMPS = Compare string	1111001z	1010011w			5+22n	
SCAS = Scan string	1111001z	1010111w			5+15n	
LODS = Load string	11110010	1010110w			6+11n	
STOS = Store string	11110010	1010101w			6+9n	
INS = Input string	11110010	0110110w			8+8n	
OUTS = Output string	11110010	0110111w			8+8n	
CONTROL TRANSFER						
CALL = Call:						
Direct within segment	11101000	disp-low	disp-high		15	
Register/memory indirect within segment	11111111	mod 010 r/m			13/19	
Direct intersegment	10011010	segment offset			23	
		segment selector				
Indirect intersegment	11111111	mod 011 r/m	(mod ≠ 11)		38	
JMP = Unconditional jump:						
Short/long	11101011	disp-low			14	
Direct within segment	11101001	disp-low	disp-high		14	
Register/memory indirect within segment	11111111	mod 100 r/m			11/17	
Direct intersegment	11101010	segment offset			14	
		segment selector				
Indirect intersegment	11111111	mod 101 r/m	(mod ≠ 11)		26	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
RET = **Return from CALL:**						
Within segment	11000011				16	
Within seg adding immed to SP	11000010	data-low	data-high		18	
Intersegment	11001011				22	
Intersegment adding immediate to SP	11001010	data-low	data-high		25	
JE/JZ = Jump on equal/zero	01110100	disp			4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100	disp			4/13	
JLE/JNG = Jump on less or equal/not greater	01111110	disp			4/13	
JB/JNAE = Jump on below/not above or equal	01110010	disp			4/13	
JBE/JNA = Jump on below or equal/not above	01110110	disp			4/13	
JP/JPE = Jump on parity/parity even	01111010	disp			4/13	
JO = Jump on overflow	01110 000	disp			4/13	
JS = Jump on sign	01111000	disp			4/13	
JNE/JNZ = Jump on not equal/not zero	01110101	disp			4/13	
JNL/JGE = Jump on not less/greater or equal	01111101	disp			4/13	
JNLE/JG = Jump on not less or equal/greater	01111111	disp			4/13	
JNB/JAE = Jump on not below/above or equal	01110011	disp			4/13	
JNBE/JA = Jump on not below or equal/above	01110111	disp			4/13	
JNP/JPO = Jump on not par/par odd	01111011	disp			4/13	
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					15	
L = 1					25	
L > 1					22+16(n−1)	
LEAVE = Leave Procedure	11001001				8	
INT = **Interrupt:**						
Type specified	11001101	type			47	
Type 3	11001100				45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	11001110				48/4	
IRET = Interrupt return	11001111				28	
BOUND = Detect value out of range	01100010	mod reg r/m			33–35	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

STI = Set interrupt	11111011		2	
HLT = Halt	11110100		2	
WAIT = Wait	10011011		6	if TEST = 0
LOCK = Bus lock prefix	11110000		2	
ESC = Processor Extension Escape	11011TTT	mod LLL r/m	6	
	(TTT LLL are opcode to processor extension)			
NOP = No Operation	10010000		3	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

REVISION HISTORY

The sections significantly revised since version -010 are:

Pin Description Table	Added note to $\overline{TEST}$ pin requiring proper RESET at power-up to configure pin as input.
	Renamed pin 44 to INT1/$\overline{SELECT}$ and pin 41 to INT3/$\overline{INTA}$1/IRQ to better describe their functions in Slave Mode.
Initialization and Processor Reset	Added reminder to drive$\overline{RES}$ pin LOW during power-up.
Major Cycle Timing Waveform	Clarified applicability of T_{CLCSV} to latched A1 and A2 in footnote.
HOLD/HLDA Timing Waveforms	Redrawn to indicate correct relationship of HOLD inactive to HLDA inactive.
Slave Mode Operation	The three low order bits associated with vector generation and performing EOI are not alterable; however, the priority levels are programmable. This information is a clarification only.

The sections significantly revised since version -009 are:

Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity.
A.C. Characteristics	Added reminder that T_{SRYCL} and T_{CLSRY} must be met.
Explanation of the A.C. Symbols	New section.
Major Cycle Timing Waveforms	T_{CLRO} indicated.

The sections significantly revised since version -008 are:

Pin Description Table	Noted $\overline{RES}$ to be low more than 4 clocks. Connections to X1 and X2 clarified.
DMA Control Bit Descriptions	Moved and clarified note concerning TC condition for ST/$\overline{STOP}$ clearing during unsynchronized transfers.
Interrupt Controller, etc.	Renamed iRMX Mode to Slave Mode.
Interrupt Request Register	Noted that D0 and D1 are read/write, others read-only.
Execution Timings	Effect of bus width clarified.

The sections significantly revised since the October, 1986 version -007 are:

A.C. Characteristics	Deleted column for 12.5 MHz devices. Intel never marketed a 12.5 MHz 80186.

The sections significantly revised since the February, 1986 version -007 are:

A.C. Characteristics	Several timings changed in anticipation of test change (all listed in ns): T_{CLAV} (min.) at 10 MHz from 50 to 44; T_{CVCTV} (min.) at 8 MHz from 10 to 5; T_{CVCTV} (max.) from 70 to 50 at 8 MHz and 56 to 40 at 10 MHz.

REVISION HISTORY

The sections significantly revised since version -010 are:

Pin Description Table	Added note to $\overline{TEST}$ pin requiring proper RESET at power-up to configure pin as input.
	Renamed pin 44 to INT1/$\overline{SELECT}$ and pin 41 to INT3/$\overline{INTA1}$/IRQ to better describe their functions in Slave Mode.
Initialization and Processor Reset	Added reminder to drive $\overline{RES}$ pin LOW during power-up.
Major Cycle Timing Waveforms	Clarified applicability of TCLCSV to latched A1 and A2 in footnote.
HOLD/HLDA Timing Waveforms	Redrawn to indicate correct relationship of HOLD inactive to HLDA inactive.
Slave Mode Operation	The three low order bits associated with vector generation and performing EOI are not alterable; however, the priority levels are programmable. This information is a clarification only.

The sections significantly revised since version -009 are:

Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity.
A.C. Characteristics	Added reminder that TSRYCL and TCLSRY must be met.
Explanation of the A.C. Symbols	New section.
Major Cycle Timing Waveforms	TCLRO indicated.

The sections significantly revised since version -008 are:

Pin Description Table	Noted $\overline{RES}$ to be low more than 4 clocks. Connections to X1 and X2 clarified.
DMA Control Bit Description	Moved and clarified note concerning TC condition for ST/$\overline{STOP}$ clearing during unsynchronized transfers.
Interrupt Controller, etc.	Renamed iRMX Mode to Slave Mode.
Interrupt Request Register	Noted that D0 and D1 are read/write, others read-only.
Execution Timings	Effect of bus width clarified.

The sections significantly revised since the October, 1986 version -007 are:

A.C. Characteristics	Deleted column for 12.5 MHz devices. Intel never marketed a 12.5 MHz 80186.

The sections significantly revised since the February, 1986 version -007 are:

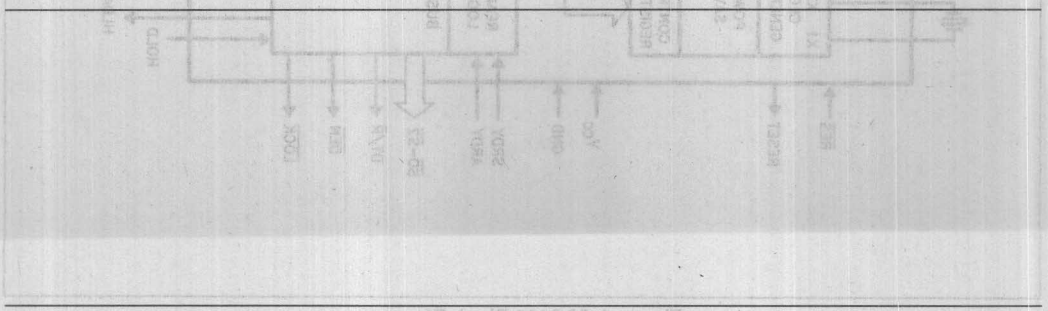
A.C. Characteristics	Several timings changed in anticipation of test change (all listed in ns): TCLAV (min.) at 10 MHz from 50 to 44; TCVCTV (min.) at 8 MHz from 10 to 5; TCVCTV (max.) from 70 to 50 at 8 MHz and 58 to 40 at 10 MHz.

- **Integrated Feature Set**
  - **— Enhanced 80C86/C88 CPU**
  - **— Clock Generator**
  - **— 2 Independent DMA Channels**
  - **— Programmable Interrupt Controller**
  - **— 3 Programmable 16-Bit Timers**
  - **— Dynamic RAM Refresh Control Unit**
  - **— Programmable Memory and Peripheral Chip Select Logic**
  - **— Programmable Wait State Generator**
  - **— Local Bus Controller**
  - **— Power Save Mode**
  - **— System-Level Testing Support (High Impedance Test Mode)**
- **Available in 16 MHz (80C186-16), 12.5 MHz (80C186-12) and 10 MHz (80C186) Versions**
- **Direct Addressing Capability to 1 MByte Memory and 64 KByte I/O**
- **Pascal-86, Fortran-86, C-86, and System Utilities**
  - **— In-Circuit-Emulator (ICE™-186)**
- **High Performance Numeric Coprocessing Capability through 80C187 Interface**
- **Available in 68 Pin:**
  - **— Plastic Leaded Chip Carrier (PLCC)**
  - **— Ceramic Pin Grid Array (PGA)**
  - **— Ceramic Leadless Chip Carrier (JEDEC A Package)**

  (See Packaging Outlines and Dimensions, Order Number 231369)
- **Available in EXPRESS Extended Temperature Range (−40°C to +85°C)**
- **Available in Military:**
  - **— Different Specifications**
  - **— 10 MHz (M80C186-10) and 12.5 MHz (M80C186-12) Versions**

  (See M80C186 data sheet, Order Number 270500 for specifications)

The Intel 80C186 is a CHMOS high integration microprocessor. It has features which are new to the 80186 family which include a DRAM refresh control unit, power-save mode and a direct numerics interface. When used in "compatible" mode, the 80C186 is 100% pin-for-pin compatible with the NMOS 80186 (except for 8087 applications). The "enhanced" mode of operation allows the full feature set of the 80C186 to be used. The 80C186 is upward compatible with 8086 and 8088 software and fully compatible with 80186 and 80188 software.



October 1989
Order Number: 270354-005

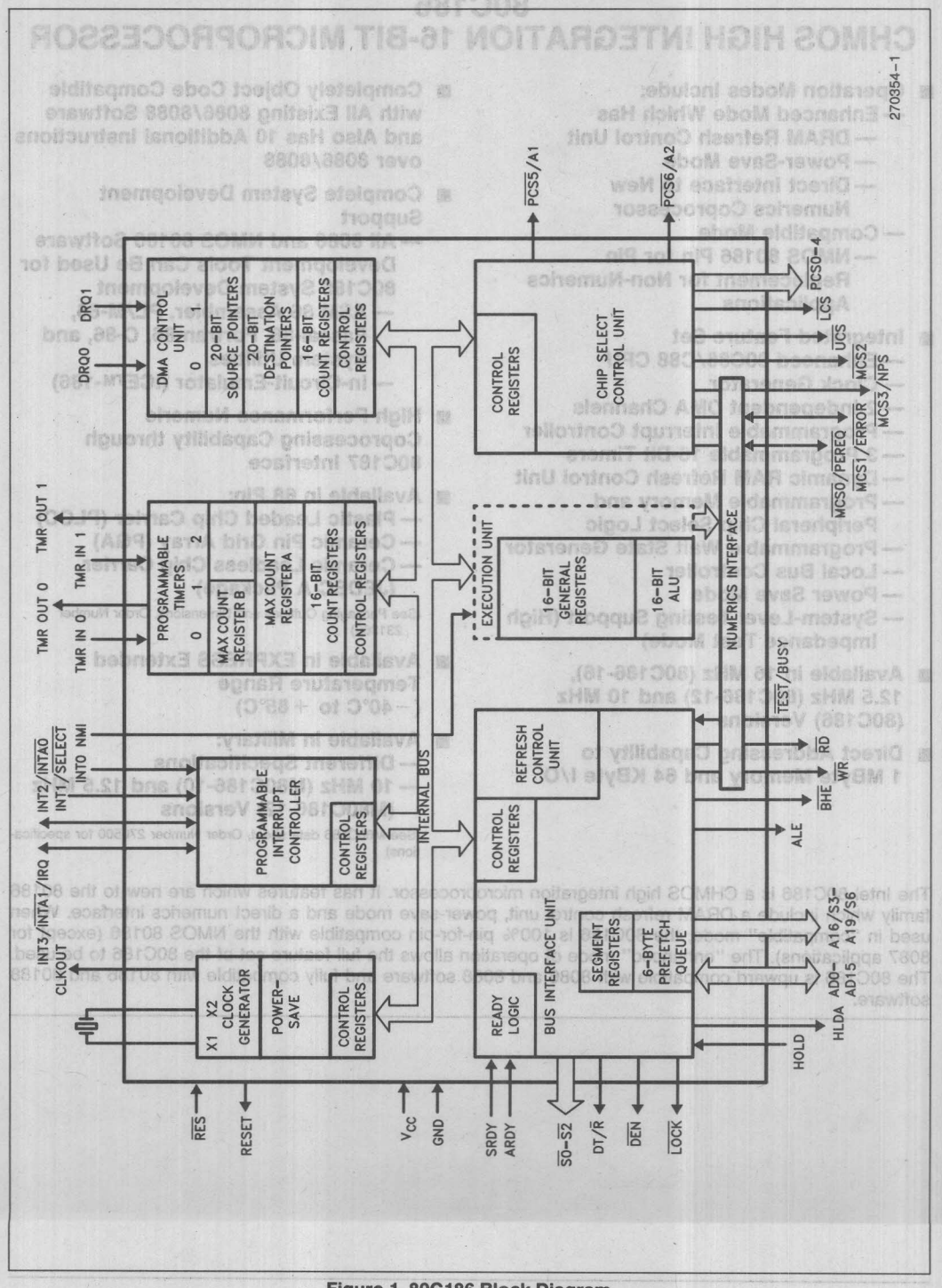


Figure 1. 80C186 Block Diagram

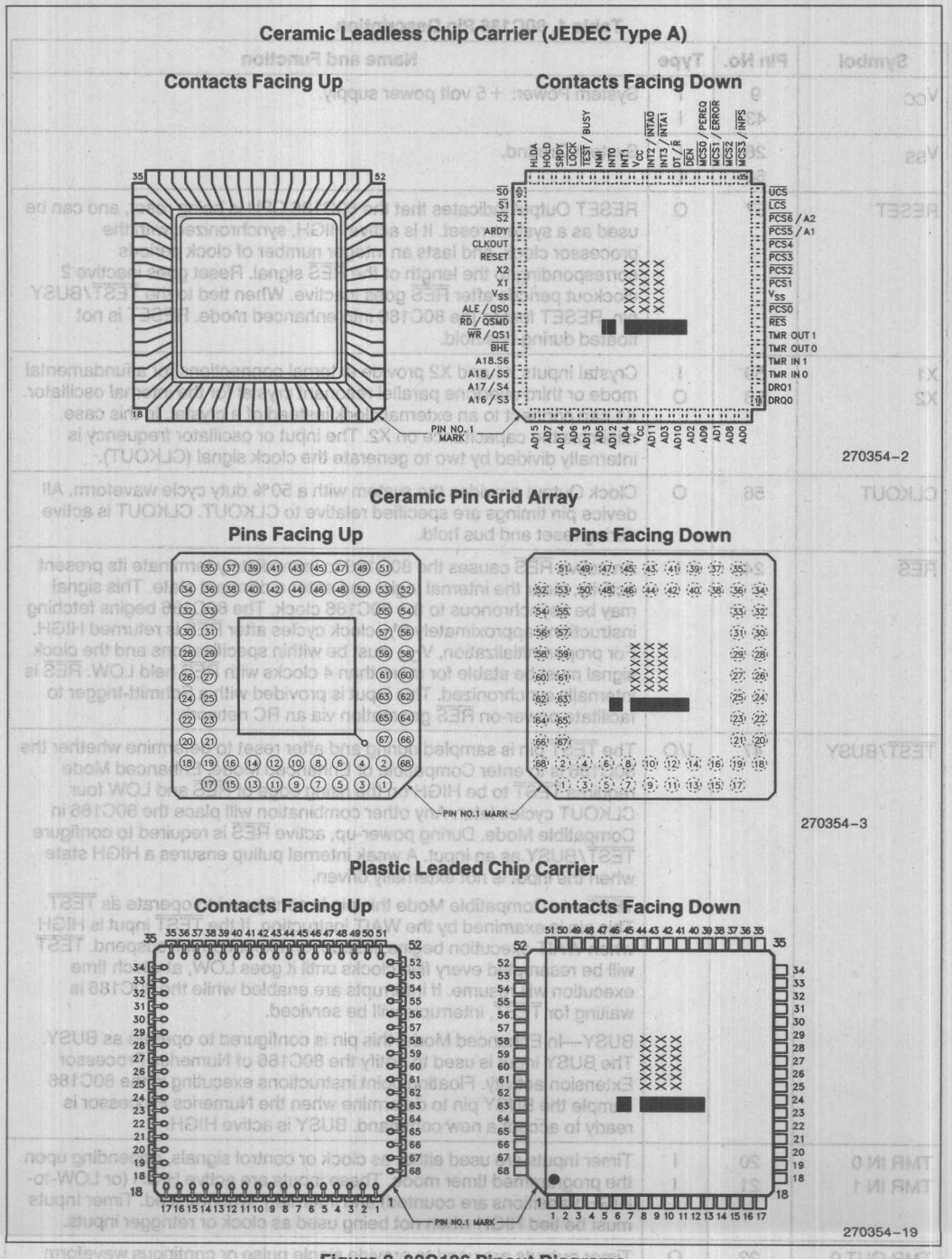


Figure 2. 80C186 Pinout Diagrams

Table 1. 80C186 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	9 43	I I	System Power: +5 volt power supply.
V_{SS}	26 60	I I	System Ground.
RESET	57	O	RESET Output indicates that the 80C186 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal. Reset goes inactive 2 clockout periods after $\overline{RES}$ goes inactive. When tied to the $\overline{TEST}$/BUSY pin, RESET forces the 80C186 into enhanced mode. RESET is not floated during bus hold.
X1 X2	59 58	I O	Crystal Inputs X1 and X2 provide external connections for a fundamental mode or third overtone parallel resonant crystal for the internal oscillator. X1 can connect to an external clock instead of a crystal. In this case, minimize the capacitance on X2. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	Clock Output provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT. CLKOUT is active during reset and bus hold.
$\overline{RES}$	24	I	An active $\overline{RES}$ causes the 80C186 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80C186 clock. The 80C186 begins fetching instructions approximately 6½ clock cycles after $\overline{RES}$ is returned HIGH. For proper initialization, V_{CC} must be within specifications and the clock signal must be stable for more than 4 clocks with $\overline{RES}$ held LOW. $\overline{RES}$ is internally synchronized. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network.
$\overline{TEST}$/BUSY	47	I/O	The $\overline{TEST}$ pin is sampled during and after reset to determine whether the 80C186 is to enter Compatible or Enhanced Mode. Enhanced Mode requires $\overline{TEST}$ to be HIGH on the rising edge of $\overline{RES}$ and LOW four CLKOUT cycles later. Any other combination will place the 80C186 in Compatible Mode. During power-up, active $\overline{RES}$ is required to configure $\overline{TEST}$/BUSY as an input. A weak internal pullup ensures a HIGH state when the input is not externally driven. $\overline{TEST}$—In Compatible Mode this pin is configured to operate as $\overline{TEST}$. This pin is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when WAIT execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled every five clocks until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80C186 is waiting for $\overline{TEST}$, interrupts will be serviced. BUSY—In Enhanced Mode, this pin is configured to operate as BUSY. The BUSY input is used to notify the 80C186 of Numerics Processor Extension activity. Floating point instructions executing in the 80C186 sample the BUSY pin to determine when the Numerics Processor is ready to accept a new command. BUSY is active HIGH.
TMR IN 0 TMR IN 1	20 21	I I	Timer Inputs are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized. Timer Inputs must be tied HIGH when not being used as clock or retrigger inputs.
TMR OUT 0 TMR OUT 1	22 23	O O	Timer outputs are used to provide single pulse or continous waveform generation, depending upon the timer mode selected. These outputs are not floated during a bus hold.

Table 1. 80C186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
DRQ0 DRQ1	18 19	I I	DMA Request is asserted HIGH by an external device when it is ready for DMA Channel 0 or 1 to perform a transfer. These signals are level-triggered and internally synchronized.
NMI	46	I	The Non-Maskable Interrupt input causes a Type 2 interrupt. An NMI transition from LOW to HIGH is latched and synchronized internally, and initiates the interrupt at the next instruction boundary. NMI must be asserted for at least one CLKOUT period. The Non-Maskable Interrupt cannot be avoided by programming.
INT0 INT1/$\overline{\text{SELECT}}$ INT2/$\overline{\text{INTA0}}$ INT3/$\overline{\text{INTA1}}$/IRQ	45 44 42 41	I I I/O I/O	Maskable Interrupt Requests can be requested by activating one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowledged. When Slave Mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).
A19/S6 A18/S5 A17/S4 A16/S3	65 66 67 68	O O O O	Address Bus Outputs (16–19) and Bus Cycle Status (3–6) indicate the four most significant address bits during T_1. These signals are active HIGH. During T_2, T_3, T_W, and T_4, the S6 pin is LOW to indicate a CPU-initiated bus cycle or HIGH to indicate a DMA-initiated bus cycle. During the same T-states, S3, S4, and S5 are always LOW. These outputs are floated during bus hold or reset.
AD15 AD14 AD13 AD12 AD11 AD10 AD9 AD8 AD7 AD6 AD5 AD4 AD3 AD2 AD1 AD0	1 3 5 7 10 12 14 16 2 4 6 8 11 13 15 17	I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O I/O	Address/Data Bus (0–15) signals constitute the time multiplexed memory or I/O address (T_1) and data (T_2, T_3, T_W, and T_4) bus. The bus is active HIGH. A_0 is analogous to $\overline{\text{BHE}}$ for the lower byte of the data bus, pins D_7 through D_0. It is LOW during T_1 when a byte is to be transferred onto the lower portion of the bus in memory or I/O operations. These pins are floated during a bus hold or reset.

Table 1. 80C186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{BHE}$	64	O	The $\overline{BHE}$ (Bus High Enable) signal is analogous to A0 in that it is used to enable data on to the most significant half of the data bus, pins D15–D8. $\overline{BHE}$ will be LOW during T_1 when the upper byte is transferred and will remain LOW through T_3 AND T_W. $\overline{BHE}$ does not need to be latched. $\overline{BHE}$ will float during HOLD or RESET. In Enhanced Mode, $\overline{BHE}$ will also be used to signify DRAM refresh cycles. A refresh cycle is indicated by both $\overline{BHE}$ and A0 being HIGH.
			$\overline{BHE}$ and A0 Encodings
			$\overline{BHE}$ Value / **A0 Value** / **Function** 0 / 0 / Word Transfer 0 / 1 / Byte Transfer on upper half of data bus (D15–D8) 1 / 0 / Byte Transfer on lower half of data bus (D_7–D_0) 1 / 1 / Refresh
ALE/QS0	61	O	Address Latch Enable/Queue Status 0 is provided by the 80C186 to latch the address. ALE is active HIGH, with addresses guaranteed valid on the trailing edge.
$\overline{WR}$/QS1	63	O	Write Strobe/Queue Status 1 indicates that the data on the bus is to be written into a memory or an I/O device. It is active LOW, and floats during bus hold or reset. When the 80C186 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction.
			QS1 / **QS0** / **Queue Operation** 0 / 0 / No queue operation 0 / 1 / First opcode byte fetched from the queue 1 / 1 / Subsequent byte fetched from the queue 1 / 0 / Empty the queue
$\overline{RD}$/$\overline{QSMD}$	62	O/I	Read Strobe is an active LOW signal which indicates that the 80C186 is performing a memory or I/O read cycle. It is guaranteed not to go LOW before the A/D bus is floated. An internal pull-up ensures that $\overline{RD}$/$\overline{QSMD}$ is HIGH during RESET. Following RESET the pin is sampled to determine whether the 80C186 is to provide ALE, $\overline{RD}$, and $\overline{WR}$, or queue status information. To enable Queue Status Mode, $\overline{RD}$ must be connected to GND. $\overline{RD}$ will float during bus HOLD.
ARDY	55	I	Asynchronous Ready informs the 80C186 that the addressed memory space or I/O device will complete a data transfer. The ARDY pin accepts a rising edge that is asynchronous to CLKOUT and is active HIGH. The falling edge of ARDY must be synchronized to the 80C186 clock. Connecting ARDY HIGH will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the SRDY pin.
SRDY	49	I	Synchronous Ready informs the 80C186 that the addressed memory space or I/O device will complete a data transfer. The SRDY pin accepts an active-HIGH input synchronized to CLKOUT. The use of SRDY allows a relaxed system timing over ARDY. This is accomplished by elimination of the one-half clock cycle required to internally synchonize the ARDY input signal. Connecting SRDY high will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the ARDY pin.

Table 1. 80C186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{LOCK}$	48	O	$\overline{LOCK}$ output indicates that other system bus masters are not to gain control of the system bus. $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is requested by the LOCK prefix instruction and is activated at the beginning of the first data cycle associated with the instruction immediately following the LOCK prefix. It remains active until the completion of that instruction. No instruction prefetching will occur while $\overline{LOCK}$ is asserted. $\overline{LOCK}$ floats during bus hold or reset.
$\overline{S0}$ $\overline{S1}$ $\overline{S2}$	52 53 54	O O O	Bus cycle status $\overline{S0}$–$\overline{S2}$ are encoded to provide bus-transaction information: **80C186 Bus Cycle Status Information** $\overline{S2}$ $\overline{S1}$ $\overline{S0}$ — Bus Cycle Initiated 0 0 0 — Interrupt Acknowledge 0 0 1 — Read I/O 0 1 0 — Write I/O 0 1 1 — Halt 1 0 0 — Instruction Fetch 1 0 1 — Read Data from Memory 1 1 0 — Write Data to Memory 1 1 1 — Passive (no bus cycle) The status pins float during HOLD. $\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator.
HOLD HLDA	50 51	I O	HOLD indicates that another bus master is requesting the local bus. The HOLD input is active HIGH. The 80C186 generates HLDA (HIGH) in response to a HOLD request. Simultaneous with the issuance of HLDA, the 80C186 will float the local bus and control lines. After HOLD is detected as being LOW, the 80C186 will lower HLDA. When the 80C186 needs to run another bus cycle, it will again drive the local bus and control lines. In Enhanced Mode, HLDA will go low when a DRAM refresh cycle is pending in the 80C186 and an external bus master has control of the bus. It will be up to the external master to relinquish the bus by lowering HOLD so that the 80C186 may execute the refresh cycle.
$\overline{UCS}$	34	O/I	Upper Memory Chip Select is an active LOW output whenever a memory reference is made to the defined upper portion (1K–256K block) of memory. $\overline{UCS}$ does not float during bus hold. The address range activating $\overline{UCS}$ is software programmable. $\overline{UCS}$ and $\overline{LCS}$ are sampled upon the rising edge of $\overline{RES}$. If both pins are held low, the 80C186 will enter ONCE Mode. In ONCE Mode all pins assume a high impedance state and remain so until a subsequent RESET. $\overline{UCS}$ has a weak internal pullup that is active during RESET to ensure that the 80C186 does not enter ONCE mode inadvertently.

Table 1. 80C186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{LCS}$	33	O/I	Lower Memory Chip Select is active LOW whenever a memory reference is made to the defined lower portion (1K–256K) of memory. $\overline{LCS}$ does not float during bus HOLD. The address range activating $\overline{LCS}$ is software programmable. $\overline{UCS}$ and $\overline{LCS}$ are sampled upon the rising edge of $\overline{RES}$. If both pins are held low, the 80C186 will enter ONCE Mode. In ONCE Mode all pins assume a high impedance state and remain so until a subsequent RESET. $\overline{LCS}$ has a weak internal pullup that is active only during RESET to ensure that the 80C186 does not enter ONCE mode inadvertently.
$\overline{MCS0}$/PEREQ $\overline{MCS1}$/$\overline{ERROR}$ $\overline{MCS2}$ $\overline{MCS3}$/$\overline{NPS}$	38 37 36 35	O/I O/I O O	Mid-Range Memory Chip Select signals are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines do not float during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable. In Enhanced Mode, $\overline{MCS0}$ becomes a PEREQ input (Processor Extension Request). When connected to the Numerics Processor Extension, this input is used to signal the 80C186 when to make numeric data transfers to and from the NPX. $\overline{MCS3}$ becomes $\overline{NPS}$ (Numeric Processor Select) which may only be activated by communication to the Numerics Processor Extension. $\overline{MCS1}$ becomes $\overline{ERROR}$ in enhanced mode and is used to signal numerics coprocessor errors. $\overline{MCS0}$/PEREQ and $\overline{MCS1}$/$\overline{ERROR}$ have weak internal pullups which are active during reset.
$\overline{PCS0}$ $\overline{PCS1}$ $\overline{PCS2}$ $\overline{PCS3}$ $\overline{PCS4}$	25 27 28 29 30	O O O O O	Peripheral Chip Select signals 0–4 are active LOW when a reference is made to the defined peripheral area (64K byte I/O or 1 MByte memory space). These lines do not float during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	Peripheral Chip Select 5 or Latched A1 may be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software-programmable. $\overline{PCS5}$/A1 does not float during bus HOLD. When programmed to provide latched A1, this pin will retain the previously latched value during HOLD.
$\overline{PCS6}$/A2	32	O	Peripheral Chip Select 6 or Latched A2 may be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software-programmable. $\overline{PCS6}$/A2 does not float during bus HOLD. When programmed to provide latched A2, this pin will retain the previously latched value during HOLD.
DT/$\overline{R}$	40	O	Data Transmit/Receive controls the direction of data flow through an external data bus transceiver. When LOW, data is transferred to the 80C186. When HIGH the 80C186 places write data on the data bus. DT/$\overline{R}$ floats during a bus hold or reset.
$\overline{DEN}$	39	O	Data Enable is provided as a data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access (including 80C187 access). $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state. During RESET, $\overline{DEN}$ is driven HIGH for one clock, then floated. $\overline{DEN}$ also floats during HOLD.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the 80C186. The 80C186 is a very high integration 16-bit microprocessor. It combines 15–20 of the most common microprocessor system components onto one chip. The 80C186 is object code compatible with the 8086/8088 microprocessors and adds 10 new instruction types to the 8086/8088 instruction set.

The 80C186 has two major modes of operation, Compatible and Enhanced. In Compatible Mode the 80C186 is completely compatible with NMOS 80186, with the exception of 8087 support. The Enhanced mode adds three new features to the system design. These are Power-Save control, Dynamic RAM refresh, and an asynchronous Numerics Coprocessor interface.

80C186 BASE ARCHITECTURE

The 8086, 8088, 80186, and 80188 family all contain the same basic set of registers, instructions, and addressing modes. The 80C186 processor is upward compatible with the 8086 and 8088 CPUs.

Register Set

The 80C186 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

General Registers

Eight 16-bit general purpose registers may be used for arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

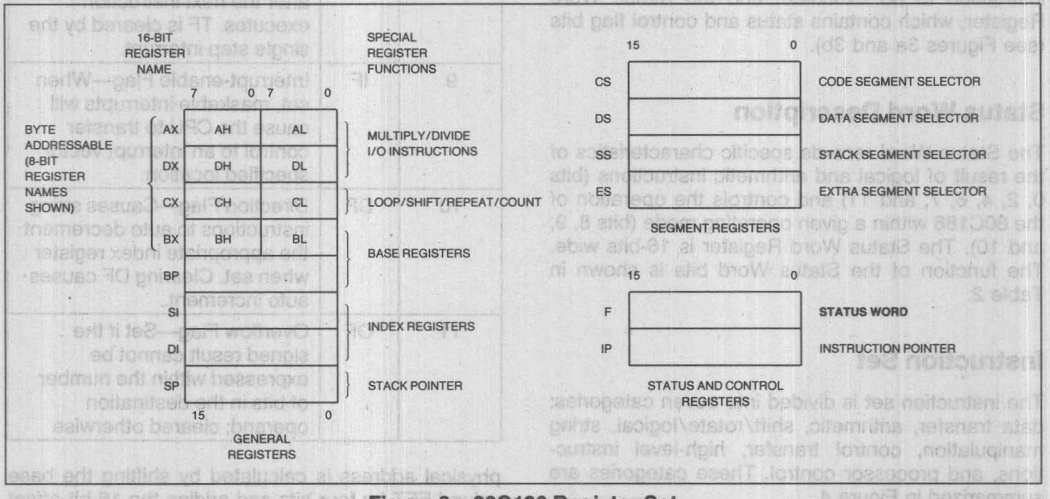


Figure 3a. 80C186 Register Set

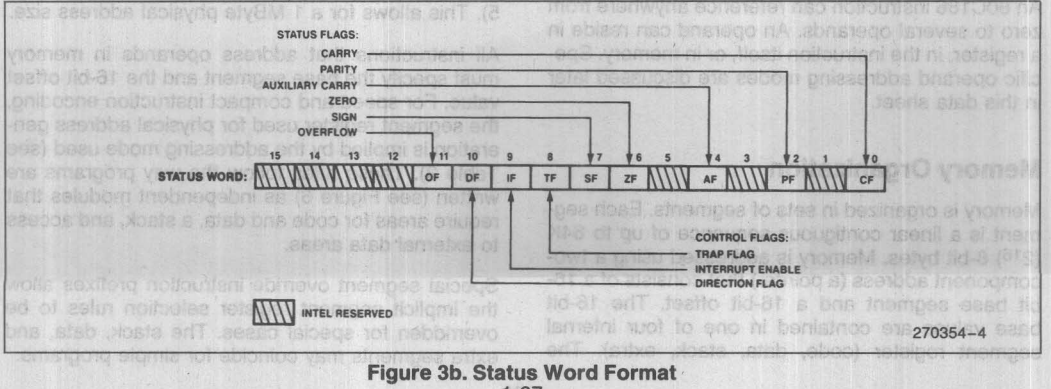


Figure 3b. Status Word Format

Segment Registers

Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers

Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Status and Control Registers

Two 16-bit special purpose registers record or alter certain aspects of the 80C186 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

Status Word Description

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80C186 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80C186 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment register (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag—Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack
ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero
LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word
FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{TEST}$ pin active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. 80C186 Instruction Set

JNC	Jump if not carry
JNE/JNZ	Jump if not equal/not zero
JNO	Jump if not overflow
JNP/JPO	Jump if not parity/parity odd
JNS	Jump if not sign

JCXZ	Jump if register CX = 0
INTERRUPTS	
INT	Interrupt
INTO	Interrupt if overflow
IRET	Interrupt return

Figure 4. 80C186 Instruction Set (Continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

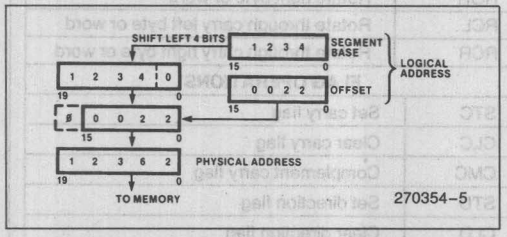


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

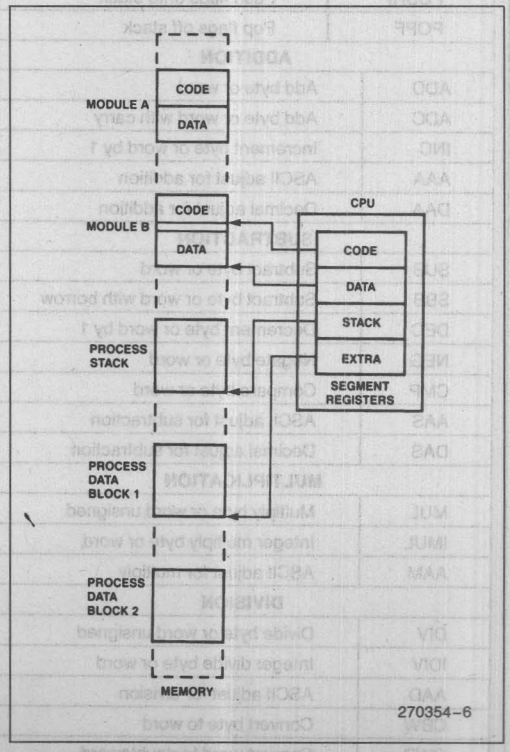


Figure 6. Segmented Memory Helps Structure Software

Addressing Modes

The 80C186 provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an Index register.
- *Based indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

Data Types

The 80C186 directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using a Numeric Data Coprocessor with the 80C186.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or a 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.
- *Floating Point:* A signed 32-, 64-, or 80-bit real number representation. (Floating point operands are supported using a Numeric Data Coprocessor with the 80C186.)

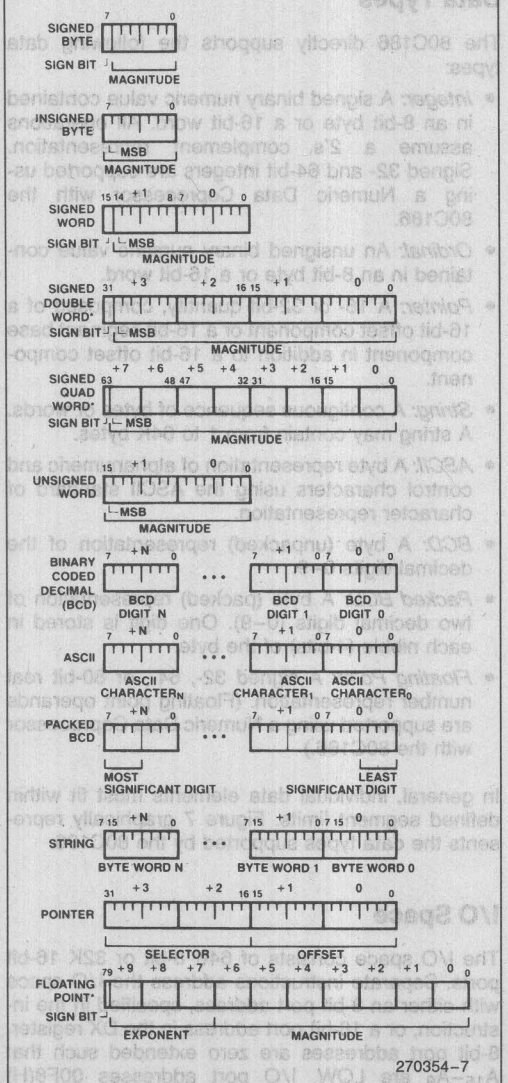
In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the 80C186.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}–A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.



NOTE:
*Supported by using a Numeric Data Coprocessor with the 80C186.

Figure 7. 80C186 Supported Data Types

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by executing an ESC instruction with the ESC trap bit set in the relocation register, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present. In all other cases, the return address from an exception will point at the instruction immediately following the instruction causing the exception.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. Table 4 shows the 80C186 predefined types and default priority levels. For each interrupt, an 8-bit vector must be supplied to the 80C186 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. In addition, internal peripherals and noncascaded external interrupts will generate their own vectors through the internal interrupt controller. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80C186 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

Those pre-defined 80C186 interrupts which cannot be masked by programming are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

SINGLE-STEP INTERRUPT (TYPE 1)

Generated after most instructions if the TF flag in the status word is set. This interrupt allows programs to execute one instruction at a time. Interrupts will not be generated after prefix instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction. Vectoring to the single-step interrupt service routine clears the TF bit. An IRET instruction in the interrupt service routine

Table 4. 80C186 Interrupt Vectors

Interrupt Name	Vector Type	Vector Address	Default Priority	Related Instructions	Applicable Notes
Divide Error Exception	0	00H	1	DIV, IDIV	1
Single Step Interrupt	1	04H	1A	All	2
Non-Maskable Interrupt (NMI)	2	08H	1	All	
Breakpoint Interrupt	3	0CH	1	INT	1
INTO Detected Overflow Exception	4	10H	1	INTO	1
Array Bounds Exception	5	14H	1	BOUND	1
Unused Opcode Exception	6	18H	1	Undefined Opcodes	1
ESC Opcode Exception	7	1CH	1	ESC Opcodes (Coprocessor)	1, 3
Timer 0 Interrupt	8	20H	2A		4
Timer 1 Interrupt	18	48H	2B		4, 6
Timer 2 Interrupt	19	4CH	2C		4, 6
Reserved	9	24H	3		
DMA 0 Interrupt	10	28H	4		6
DMA 1 Interrupt	11	2CH	5		6
INT0 Interrupt	12	30H	6		
INT1 Interrupt	13	34H	7		
INT2 Interrupt	14	38H	8		
INT3 Interrupt	15	3CH	9		
Numerics Coprocessor Exception	16	40H	1	ESC Opcodes (Numerics Coprocessor)	1, 5
Reserved	17	44H			
Reserved	20–31	50H . . . 7CH			

NOTES:
Default priorities for the interrupt sources are used only if the user does not program each source to a unique priority level.
1. Generated as a result of an instruction execution.
2. Performed in the same manner as 8086.
3. An ESC (coprocessor) opcode will cause a trap if the 80C186 is in compatible mode or if the processor is in Enhanced Mode with the proper bit set in the peripheral control block relocation register. **The 80C186 is not directly compatible with the 80186 in this respect.**
4. All three timers constitute one source of request to the interrupt controller. As such, they share the same priority level with respect to other interrupt sources. However, the timers have a defined priority order among themselves (2A > 2B > 2C).
5. Numerics coprocessor exceptions are detected by the 80C186 upon execution of a subsequent numerics instruction.
6. The vector type numbers for these sources are programmable in Slave Mode.

restores the TF bit to logic "1" and transfers control to the next instruction to be single-stepped.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)

An external interrupt source which is serviced regardless of the state of the IF bit. No external interrupt acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced. A typical use of NMI would be to activate a power failure routine.

BREAKPOINT INTERRUPT (TYPE 3)

A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INTO DETECTED OVERFLOW EXCEPTION (TYPE4)

Generated during an INTO instruction if the 0F bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)

Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)

Generated if execution is attempted on undefined opcodes.

ESCAPE OPCODE EXCEPTION (TYPE 7)

Generated if execution is attempted of ESC opcodes (D8H–DFH). In compatible mode operation, ESC opcodes will always generate this exception. In enhanced mode operation, the exception will be generated only if a bit in the relocation register is set. The return address of this exception will point to the ESC instruction causing the exception. If a segment override prefix preceded the ESC instruction, the return address will point to the segment override prefix.

NOTE:
80C186 processing of ESC (numerics coprocessor) opcodes differs substantially from the 80186.

NUMERICS COPROCESSOR EXCEPTION (TYPE 16)

An interrupt generated in response to an unmasked error in the 80C187 Numerics Coprocessor Extension. In general, the 80C187 does not detect an error until the instruction after the error occurred. A numerics coprocessor error is signalled to the 80C187 on its $\overline{\text{ERROR}}$ input pin.

Hardware-generated interrupts are divided into two groups: maskable interrupts and non-maskable interrupts. The 80C186 provides maskable hardware interrupt request pins INT0–INT3. In addition, maskable interrupts may be generated by the 80C186 integrated DMA controller and the integrated timer unit. The vector types for these interrupts is shown in Table 4. Software enables these inputs by setting the interrupt flag bit (IF) in the Status Word. The interrupt controller is discussed in the peripheral section of this data sheet.

Further maskable interrupts are disabled while servicing an interrupt because the IF bit is reset as part of the response to an interrupt or exception. The saved Status Word will reflect the enable status of the processor prior to the interrupt. The interrupt flag will remain zero unless specifically set. The interrupt return instruction restores the Status Word, thereby restoring the original status of IF bit. If the interrupt return re-enables interrupts, and another interrupt is pending, the 80C186 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Initialization and Processor Reset

Processor initialization is accomplished by driving the $\overline{\text{RES}}$ input pin LOW. $\overline{\text{RES}}$ must be LOW during power-up to ensure proper device initialization. $\overline{\text{RES}}$ forces the 80C186 to terminate all execution and local bus activity. No instruction or bus activity will occur as long as $\overline{\text{RES}}$ is active. After $\overline{\text{RES}}$ becomes inactive and an internal processing interval elapses, the 80C186 begins execution with the instruction at physical location FFFF0(H). $\overline{\text{RES}}$ also sets some registers to predefined values as shown in Table 5.

Table 5. 80C186 Initial Register State after RESET

Status Word	F002(H)
Instruction Pointer	0000(H)
Code Segment	FFFF(H)
Data Segment	0000(H)
Extra Segment	0000(H)
Stack Segment	0000(H)
Relocation Register	20FF(H)
UMCS	FFFB(H)

80C186 CLOCK GENERATOR

The 80C186 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The 80C186 oscillator circuit is designed to be used either with a parallel resonant fundamental or third-overtone mode crystal, depending upon the frequency range of the application as shown in Figure 8c. This is used as the time base for the 80C186. The crystal frequency chosen should be twice the required processor frequency. Use of an LC or RC circuit is not recommended.

The output of the oscillator is not directly available outside the 80C186. The two recommended crystal configurations are shown in Figures 8a and 8b. When used in third-overtone mode the tank circuit shown in Figure 8b is recommended for stable operation. The sum of the stray capacitances and load-

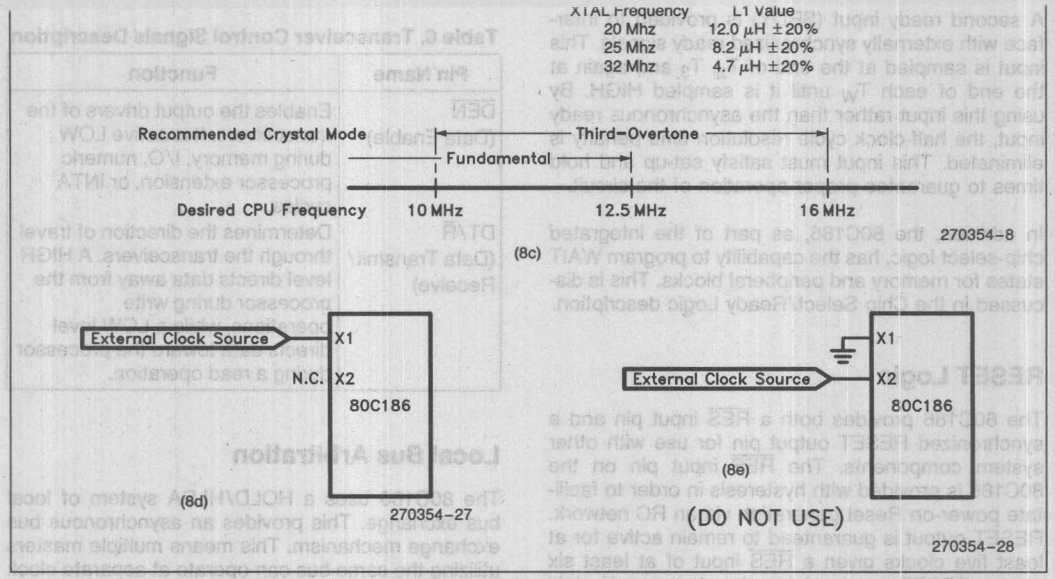


Figure 8. 80C186 Oscillator Configurations (see text)

ing capacitors should equal the values shown. It is advisable to limit stray capacitance between the X1 and X2 pins to less than 10 pF. While a fundamental-mode circuit will require approximately 1 ms for start-up, the third-overtone arrangement may require 1 ms to 3 ms to stabilize.

Alternately, the oscillator may be driven from an external source as shown in Figure 8d. The configuration shown in Figure 8e is not recommended.

Intel recommends the following values for crystal selection parameters.

Temperature Range:	0 to 70°C
ESR (Equivalent Series Resistance):	40Ω max
C_0 (Shunt Capacitance of Crystal):	7.0 pF max
C_1 (Load Capacitance):	20 pF ± 2 pF
Drive Level:	1 mW max

Clock Generator

The 80C186 clock generator provides the 50% duty cycle processor clock for the 80C186. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the 80C186. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The 80C186 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3, and again in the middle of each T_W until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used for full synchronization of a rising ARDY signal. A high-to-low transition on ARDY may be used as an indication of the not ready condition but it must be performed synchronously to CLKOUT **either** in the middle of T_2, T_3, **or** T_W, or at the falling edge of T_3 or T_W.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3 and again at the end of each T_W until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated. This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the 80C186, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

RESET Logic

The 80C186 provides both a $\overline{RES}$ input pin and a synchronized RESET output pin for use with other system components. The $\overline{RES}$ input pin on the 80C186 is provided with hysteresis in order to facilitate power-on Reset generation via an RC network. RESET output is guaranteed to remain active for at least five clocks given a $\overline{RES}$ input of at least six clocks. RESET may be delayed up to approximately two and one-half clocks behind $\overline{RES}$.

LOCAL BUS CONTROLLER

The 80C186 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides outputs that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The 80C186 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory or I/O to the 80C186 or to strobe data from the 80C186 to memory or I/O. The ALE line provides a strobe to latch the address when it is valid. The 80C186 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The 80C186 generates two control signals for external transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

Table 6. Transceiver Control Signals Description

Pin Name	Function
$\overline{DEN}$ (Data Enable)	Enables the output drivers of the transceivers. It is active LOW during memory, I/O, numeric processor extension, or INTA cycles.
DT/$\overline{R}$ (Data Transmit/ Receive)	Determines the direction of travel through the transceivers. A HIGH level directs data away from the processor during write operations, while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The 80C186 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The 80C186 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. External circuitry must arbitrate which external device will gain control of the bus when there is more than one alternate local bus master. When the 80C186 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$–$\overline{S2}$, $\overline{LOCK}$, AD0–AD15, A16–A19, $\overline{BHE}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The 80C186 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is second only to DRAM refresh requests in priority of activity requests the processor may receive. Any bus cycle in progress will be completed before the 80C186 relinquishes the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency can be as great as 4 bus cycles. This will occur if a DMA word trans-

fer operation is taking place from an odd address to an odd address. This is a total of 16 clock cycles or more if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

If the 80C186 has relinquished the bus and a refresh request is pending, HLDA is removed (driven low) to signal the remote processor that the 80C186 wishes to regain control of the bus. The 80C186 will wait until HOLD is removed before taking control of the bus to run the refresh cycle.

Local Bus Controller and Reset

During RESET the local bus controller will perform the following action:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float them.
- Drive $\overline{S0}$–$\overline{S2}$ to the inactive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Float AD0–15, A16–19, $\overline{BHE}$, DT/$\overline{R}$.
- Drive ALE LOW
- Drive HLDA LOW.

$\overline{RD}$/QSMD, $\overline{UCS}$, $\overline{LCS}$, $\overline{MCS0}$/PEREQ, $\overline{MCS1}$/$\overline{ERROR}$, and $\overline{TEST}$/BUSY pins have internal pullup devices which are active while $\overline{RES}$ is applied. Excessive loading or grounding certain of these pins causes the 80C186 to enter an alternative mode of operation:

- $\overline{RD}$/QSMD low results in Queue Status Mode.
- $\overline{UCS}$ and $\overline{LCS}$ low results in ONCE™ Mode.
- $\overline{TEST}$/BUSY low (and high later) results in Enhanced Mode.

INTERNAL PERIPHERAL INTERFACE

All the 80C186 integrated peripherals are controlled by 16-bit registers contained within an internal 256-byte control block. The control block may be mapped into either memory or I/O space. Internal logic will recognize control block addresses and respond to bus cycles. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{15-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80C186 CPU at any time.

The control block base address is programmed by a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. The control block is effectively an internal chip select range and must abide by all the rules concerning chip selects (the chip select circuitry is discussed later in this data sheet). Any access to the 256 bytes of the control block activates an internal chip select.

Other chip selects may overlap the control block only if they are programmed to zero wait states and ignore external ready. In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space. If the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into Slave Mode, and cause the CPU to interrupt upon encountering ESC instructions. At RESET, the relocation register is set to 20FFH, which maps the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

CHIP-SELECT/READY GENERATION LOGIC

The 80C186 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

Memory Chip Selects

The 80C186 provides 6 memory chip select outputs for 3 address areas; upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address

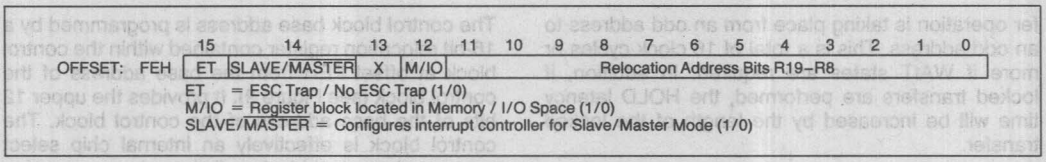


Figure 9. Relocation Register

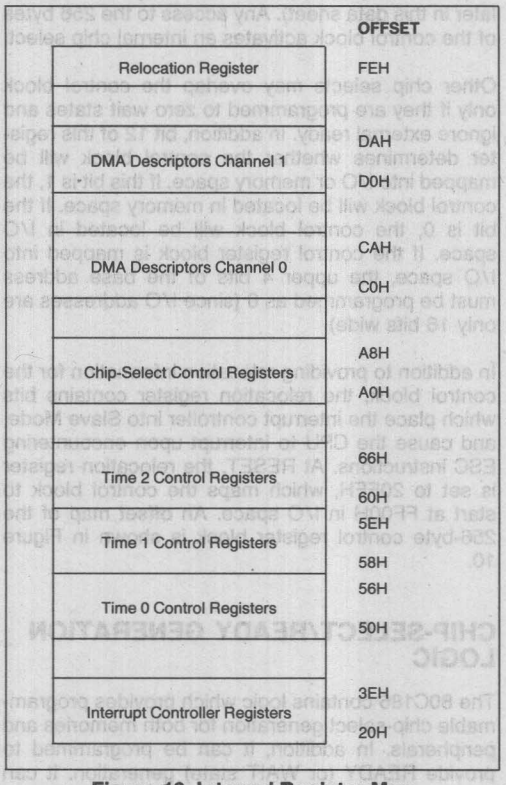


Figure 10. Internal Register Map

of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes, whereas 80C186 memory is arranged in words. This means that if, for example, 16 64K x 1 memories are used, the memory block size will be 128K, not 64K.

Upper Memory $\overline{CS}$

The 80C186 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the 80C186 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0=R1=R2=0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

The internal generation of any 20-bit address whose upper 16 bits are equal to or greater than the UMCS value (with bits 0–5 as "0") asserts $\overline{UCS}$. UMCS bits R2–R0 specify the ready mode for the area of memory defined by the chip select register, as explained later.

Lower Memory $\overline{CS}$

The 80C186 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0=R1=R2=0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12) at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After RESET, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will assert $\overline{LCS}$. LMCS register bits R2–R0 specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The 80C186 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located within the 80C186 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. If the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as described in a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14–8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After RESET, the contents of both registers are undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

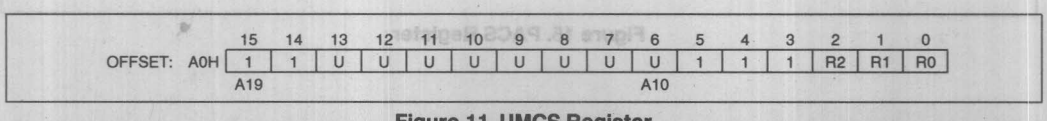


Figure 11. UMCS Register

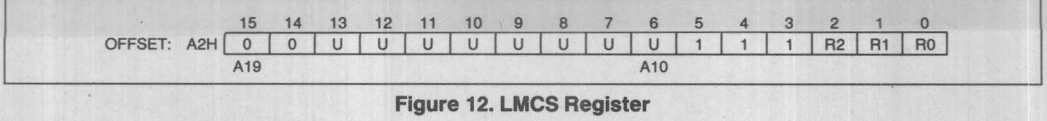


Figure 12. LMCS Register

tion for all four mid-range chip selects.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

In Enhanced Mode, three of the four $\overline{MCS}$ pins become handshaking pins for the 80C187 Numerics Processor Extension. $\overline{MCS2}$ is still available as a chip select covering one-fourth the mid-range address block, subject to the usual programming of the MPCS and MMCS registers.

Peripheral Chip Selects

The 80C186 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the 80C186. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1 and A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0 and A1 pins used for selecting internal registers of external 8-bit peripheral chips. This scheme simplifies the external hardware because the peripheral registers can be located on even boundaries in I/O or memory space.

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). The register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

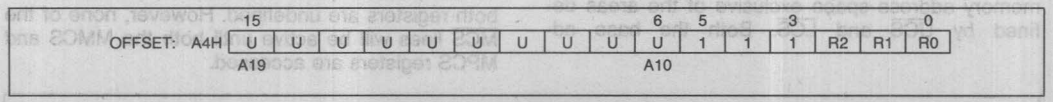


Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

$\overline{PCS}$ Line	Active between Locations
$\overline{PCS0}$	PBA —PBA + 127
$\overline{PCS1}$	PBA + 128—PBA + 255
$\overline{PCS2}$	PBA + 256—PBA + 383
$\overline{PCS3}$	PBA + 384—PBA + 511
$\overline{PCS4}$	PBA + 512—PBA + 639
$\overline{PCS5}$	PBA + 640—PBA + 767
$\overline{PCS6}$	PBA + 768—PBA + 895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 13). The register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After RESET, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space.
	0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided.
	1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 specify the READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The 80C186 can generate a READY signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the 80C186 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the 80C186. The interpretation of the READY bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal ready generator operates in parallel with external READY, not in series if the external READY is used (R2 = 0). For example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon RESET, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to insert 3 wait states in conjunction with external READY (i.e., UMCS resets to FFFBH).
- No other chip select or READY control registers have any predefined values after RESET. They will not become active until the CPU accesses their control registers. Both the PACS and MPCS registers must be accessed before the $\overline{PCS}$ lines will become active.

DMA CHANNELS

The 80C186 DMA controller provides two independent high-speed DMA channels. Data transfers can occur between memory and I/O spaces (e.g., Memory to I/O) or within the same space (e.g., Memory to Memory or I/O to I/O). Data can be transferred either in bytes (8 bits) or in words (16 bits) to or from even or odd addresses. Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer (by one or two depending on byte or word transfers). Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data.

DMA Operation

Each channel has six registers in the control block which define each channel's operation. The control registers consist of a 20-bit Source pointer (2 words), a 20-bit destination pointer (2 words), a 16-bit Transfer Count Register, and a 16-bit Control Word. The format of the DMA Control Blocks is shown in Table 13. The Transfer Count Register (TC) specifies the number of DMA transfers to be performed. Up to 64K byte or word transfers can be performed with automatic termination. The Control Word defines the channel's operation (see Figure 17). All registers may be modified or altered during any DMA activity. Any changes made to these registers will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

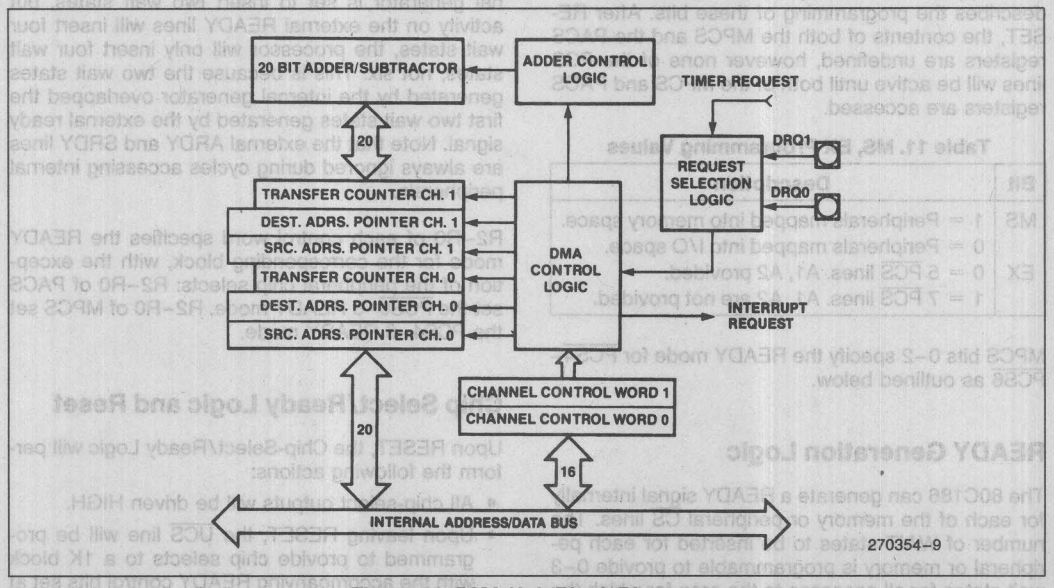


Figure 16. DMA Unit Block Diagram

- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

DEST: M/$\overline{IO}$ Destination pointer is in memory (1) or I/O (0) space.

DEC Decrement destination pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

INC Increment destination pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

If both INC and DEC are specified, the pointer will remain constant after each cycle.

SOURCE: M/$\overline{IO}$ Source pointer is in memory (1) or I/O (0) space.

DEC Decrement source pointer by 1 or 2 (depends on $\overline{B}$/W) after each transfer.

be reset at this point. If cleared, the DMA controller will decrement the transfer count register for each DMA cycle, but DMA transfers will not stop when the transfer count register reaches zero.

INT: Enable interrupts to CPU upon transfer count termination.

SYN: 00 No synchronization.

NOTE:

When unsynchronized transfers are specified, the TC bit will be ignored and the ST/$\overline{STOP}$ bit will be cleared upon the transfer count reaching zero, stopping the channel.

01 Source synchronization.

10 Destination synchronization.

11 Unused.

P: Channel priority relative to other channel during simultaneous requests.

0 Low priority.

1 High priority.

Channels will alternate cycles if both are set at same priority level.

TDRQ: Enable/Disable (1/0) DMA requests from timer 2.

CHG/$\overline{NOCHG}$: Change/Do not change (1/0) ST/$\overline{STOP}$ bit. If this bit is set when writing to the control word, the ST/$\overline{STOP}$ bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/$\overline{STOP}$ bit will not be altered. This bit is not stored; it will always be read as 0.

ST/$\overline{STOP}$: Start/Stop (1/0) channel.

$\overline{B}$/W: Byte/Word (0/1) transfers.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. For each DMA channel to be used, all four pointer registers must be initialized. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18). These pointers may be individually incremented or decremented after each transfer. If word transfers are performed the pointer is incremented or decremented by two.

Each pointer may point into either memory or I/O space. Since the upper four bits of the address are not automatically programmed to zero, the user must program them in order to address the normal 64K I/O space. Since the DMA channels can perform transfers to or from odd addresses, there is no restriction on values for the pointer registers. Higher transfer rates can be achieved if all word transfers are performed to or from even addresses so that accesses will occur in single bus cycles.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). The register is decremented after every DMA cycle, regardless of the state of the TC bit in the DMA Control Register. If the TC bit in the DMA control word is set or if unsynchronized transfers are programmed, however, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). When destination synchronization is performed, data will not be fetched from the source address until the destination device signals that it is ready to receive it. When destination synchronized transfers are requested, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another DMA cycle will begin after two processor clocks. This allows the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. Table 14 shows the maximum DMA transfer rates.

Table 14. Maximum DMA Transfer Rates at CLKOUT = 16 MHz

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	4.0MBytes/sec	4.0MBytes/sec
Source Synch	4.0MBytes/sec	4.0MBytes/sec
Destination Synch	2.7MBytes/sec	3.2MBytes/sec

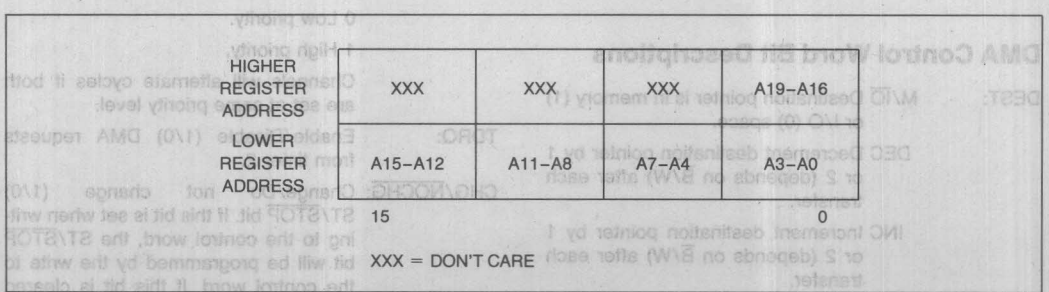


Figure 18. DMA Pointer Register Format

DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed to give one channel priority over the other, or they may be programmed to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses or word accesses to odd memory locations; also an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/$\overline{\text{STOP}}$ bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also be generated. Therefore the source and destination transfer pointers, and the transfer count register (if used) must be programmed before the ST/$\overline{\text{STOP}}$ bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/NOCHG bit is cleared when the control register is written, the ST/$\overline{\text{STOP}}$ bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the state of the DMA channels will be as follows:

- The ST/$\overline{\text{STOP}}$ bit for each channel will be reset to $\overline{\text{STOP}}$.
- Any transfer in progress is aborted.
- The values of the transfer count registers, source pointers, and destination pointers are indeterminate.

TIMERS

The 80C186 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, the third timer can be used as a prescaler to the other two, or as a DMA request source.

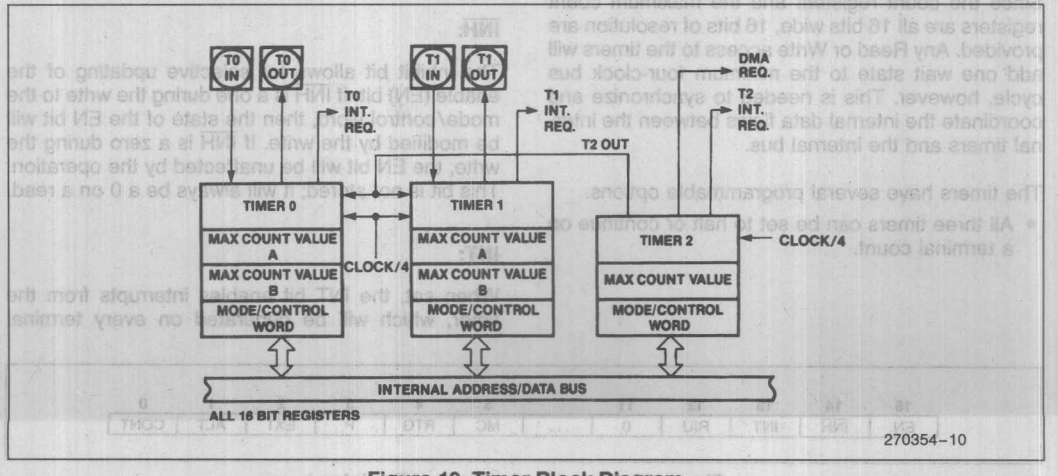


Figure 19. Timer Block Diagram

clock after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate. Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input.

Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

EN:

The enable bit provides programmer control over the timer's RUN/HALT status. When set, the timer is enabled to increment subject to the input pin constraints in the internal clock mode (discussed previously). When cleared, the timer will be inhibited from counting. All input pin transistions during the time EN is zero will be ignored. If CONT is zero, the EN bit is automatically cleared upon maximum count.

$\overline{INH}$:

The inhibit bit allows for selective updating of the enable (EN) bit. If $\overline{INH}$ is a one during the write to the mode/control word, then the state of the EN bit will be modified by the write. If $\overline{INH}$ is a zero during the write, the EN bit will be unaffected by the operation. This bit is not stored; it will always be a 0 on a read.

INT:

When set, the INT bit enables interrupts from the timer, which will be generated on every terminal

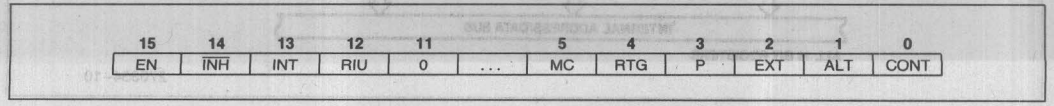


Figure 20. Timer Mode/Control Register

count. If the timer is configured in dual MAX COUNT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller).

RIU:

The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

MC:

The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts.

Programmer intervention is required to clear this bit.

RTG:

Retrigger bit is only active for internal clocking (EXT = 0). In this case it determines the control function provided by the input pin.

If RTG = 0, the input level gates the internal clock on and off. If the input pin is HIGH, the timer will count; if the input pin is LOW, the timer will hold its value. As indicated previously, the input signal may be asynchronous with respect to the 80C186 clock.

When RTG = 1, the input pin detects LOW-to-HIGH transitions. The first such transition starts the timer running, clearing the timer value to zero on the first clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

P:

The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

EXT:

The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80C186 clock.

If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

ALT:

The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT:

Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT = 1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The contents of this register may be read or written by the processor at any time. If the register is written while the timer is counting, the new value will take effect in the current count cycle.

The count registers should be programmed before attempting to use the timers since they are not automatically initialized to zero.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached. A timer resets when the timer count register equals the max count value being used. If the timer count register or the max count register is changed so that the max count is less than the timer count, the timer does not immediately reset. Instead, the timer counts up to 0FFFFH, "wraps around" to zero, counts up to the max count value, and then resets.

Timers and Reset

Upon RESET, the state of the timers will be as follows:

- All EN (Enable) bits are reset preventing timer counting.
- For Timers 0 and 1, the RIU bits are reset to zero and the ALT bits are set to one. This results in the Timer Out pins going HIGH.
- The contents of the count registers are indeterminate.

INTERRUPT CONTROLLER

The 80C186 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80C186 interrupt controller has its own control register that sets the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service routines for lower priority interrupts may be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The 80C186 has a special Slave Mode in which the internal interrupt controller acts as a slave to an external master. The controller is programmed into this mode by setting bit 14 in the peripheral control block relocation register. (See Slave Mode section.)

MASTER MODE OPERATION

Interrupt Controller External Interface

Five pins are provided for external interrupt sources. One of these pins is NMI, the non-maskable interrupt. NMI is generally used for unusual events such as power-fail interrupts. The other four pins may be configured in any of the following ways:

- As four interrupt lines with internally generated interrupt vectors.
- As an interrupt line and interrupt acknowledge line pair (Cascade Mode) with externally generated interrupt vectors plus two interrupt input lines with internally generated vectors.
- As two pairs of interrupt/interrupt acknowledge lines (Cascade Mode) with externally generated interrupt vectors.

External sources in the Cascade Mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80C186 on the second cycle. The capability to interface to external 82C59A programmable interrupt controllers is provided when the inputs are configured in Cascade Mode.

Interrupt Controller Modes of Operation

The basic modes of operation of the interrupt controller in Master Mde are similar to the 82C59A. The interrupt controller responds identically to internal interrupts in all three modes: the difference is only in the interpretation of function of the four external interrupt pins. The interrupt controller is set into one of these three modes by programming the correct bits in the INT0 and INT1 control registers. The modes of interrupt controller operation are as follows:

Fully Nested Mode

When in the fully nested mode four pins are used as direct interrupt requests as in Figure 22. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the in-service bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled, yet be suspended only by interrupts of higher priority than the in-service interrupt.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is executed at the end of the service routine just before the return from interrupt instruction. If the fully nested structure has been upheld, the next highest-priority source with its IS bit set is then serviced.

Cascade Mode

The 80C186 has four interrupt pins and two of them have dual functions. In the fully nested mode the four pins are used as direct interrupt inputs and the corresponding vectors are generated internally. In the Cascade Mode, the four pins are configured into interrupt input-dedicated acknowledge signal pairs. The interconnection is shown in Figure 23. INT0 is an interrupt input interfaced to an 82C59A, while INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the Cascade Mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary Cascade Mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 82C59As. Three levels of priority are created, requiring priority resolution in the 80C186 interrupt controller, the master 82C59As, and the slave 82C59As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

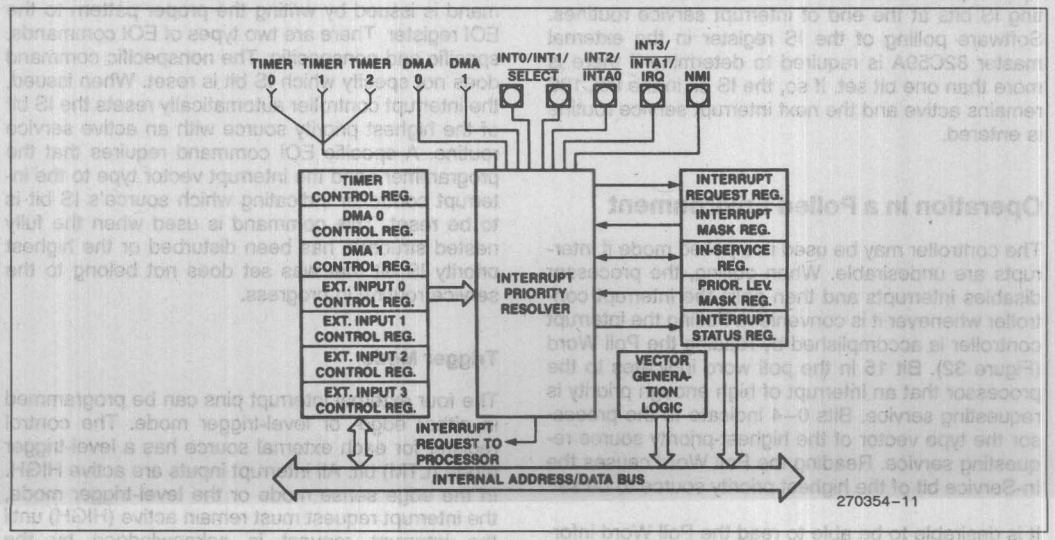


Figure 21. Interrupt Controller Block Diagram

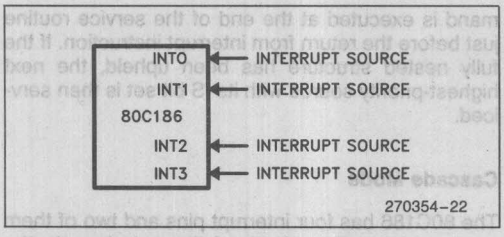


Figure 22. Fully Nested (Direct) Mode Interrupt Controller Connections

Special Fully Nested Mode

This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 82C59A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80C186 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80C186 controller until the 80C186 in-service bit is reset. In Special Fully Nested Mode, the 80C186 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80C186 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the IS register in the external master 82C59A is required to determine if there is more than one bit set. If so, the IS bit in the 80C186 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (Figure 32). Bit 15 in the poll word indicates to the processor that an interrupt of high enough priority is requesting service. Bits 0–4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80C186 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

Master Mode Features

Programmable Priority

The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority). All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, other interrupt requests can be serviced.

End-of-Interrupt Command

The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

Trigger Mode

The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the

80C186 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to re-enable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

Interrupt Vectoring

The 80C186 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Modes. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 24. It contains 15 registers. All registers can both be read or written unless specified otherwise.

In-Service Register

This register can be read from or written into. The format is shown in Figure 25. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command.

Interrupt Request Register

The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 25. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits are set when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Writes to the interrupt request register will affect the D0 and D1 interrupt request bits. Setting either bit will cause the corresponding interrupt request while clearing either bit will remove the corresponding interrupt request. All other bits in the register are read-only.

Mask Register

This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 25. A one in a bit position corre-

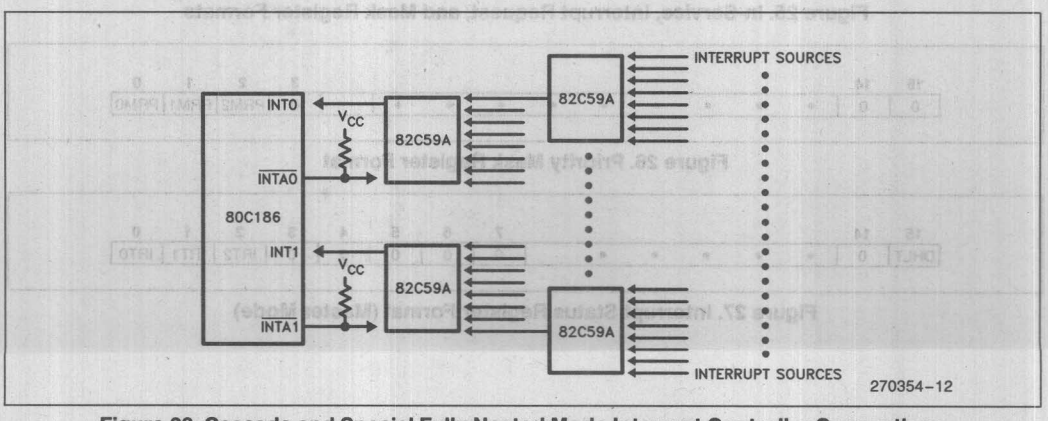


Figure 23. Cascade and Special Fully Nested Mode Interrupt Controller Connections

sponding to a particular source masks the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

	OFFSET
INT3 CONTROL REGISTER	3EH
INT2 CONTROL REGISTER	3CH
INT1 CONTROL REGISTER	3AH
INT0 CONTROL REGISTER	38H
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	34H
TIMER CONTROL REGISTER	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY MASK REGISTER	2AH
MASK REGISTER	28H
POLL STATUS REGISTER	26H
POLL REGISTER	24H
EOI REGISTER	22H

Figure 24. Interrupt Controller Registers (Master Mode)

15	14	•	•	•	10	9	8	7	6	5	4	3	2	1	0
0	0	•	•	•	0	0	0	I3	I2	I1	I0	D1	D0	0	TMR

Figure 25. In-Service, Interrupt Request, and Mask Register Formats

15	14	•	•	•	•	•	•	•	•	•		3	2	1	0
0	0	•	•	•	•	•	•	•	•	•		0	PRM2	PRM1	PRM0

Figure 26. Priority Mask Register Format

15	14	•	•	•	•	•	7	6	5	4	3	2	1	0
DHLT	0	•	•	•	•	•	0	0	0	0	0	IRT2	IRT1	IRT0

Figure 27. Interrupt Status Register Format (Master Mode)

Priority Mask Register

This register masks all interrupts below a particular interrupt priority level. The format of this register is shown in Figure 26. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so no interrupts are masked due to priority number.

Interrupt Status Register

This register contains general interrupt controller status information. The format of this register is shown in Figure 27. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. This bit allows prompt service of all non-maskable interrupts. This bit may also be set by the programmer.

IRTx: These three bits represent the individual timer interrupt request bits. These bits differentiate between timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt request. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

These registers are the control words for the four external input pins. Figure 29 shows the format of the INT0 and INT1 Control registers; Figure 30 shows the format of the INT2 and INT3 Control registers. In Cascade Mode or Special Fully Nested Mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest Priority = 000, Lowest Priority = 111

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this register is shown in Figure 31. It initiates an EOI command when written to by the 80C186 CPU.

The bits in the EOI register are encoded as follows:

S_X: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10.

NOTE:
To reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

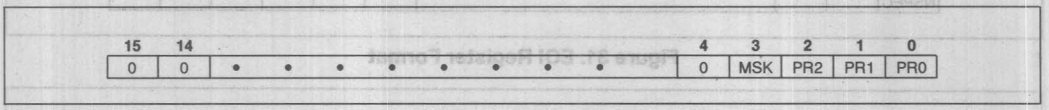


Figure 28. Timer/DMA Control Registers Formats

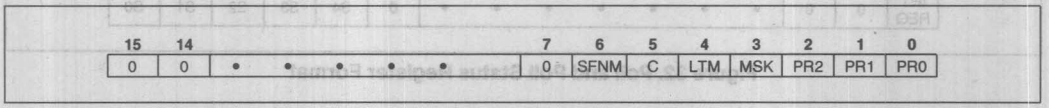


Figure 29. INT0/INT1 Control Register Formats

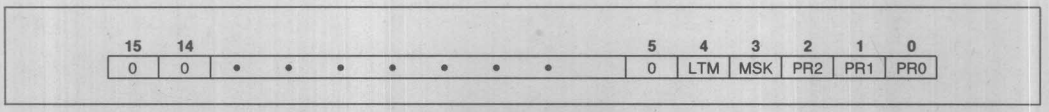


Figure 30. INT2/INT3 Control Register Formats

rupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

SLAVE MODE OPERATION

When Slave Mode is used, the internal 80C186 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80C186 resources will be monitored by the internal interrupt controller, while the external controller functions as the system master interrupt controller.

sibility to assign correct priorities and initialize interrupt control registers before enabling interrupts.

Slave Mode External Interface

The configuration of the 80C186 with respect to an external 82C59A master is shown in Figure 33. The INT0 (Pin 45) input is used as the 80C186 CPU interrupt input. IRQ (Pin 41) functions as an output to send the 80C186 slave-interrupt-request to one of the 8 master-PIC-inputs.

15	14	13							5	4	3	2	1	0
SPEC/ NSPEC	0	0	•	•	•	•	•	•	0	S4	S3	S2	S1	S0

Figure 31. EOI Register Format

15	14	13							5	4	3	2	1	0
INT REQ	0	0	•	•	•	•	•	•	0	S4	S3	S2	S1	S0

Figure 32. Poll and Poll Status Register Format

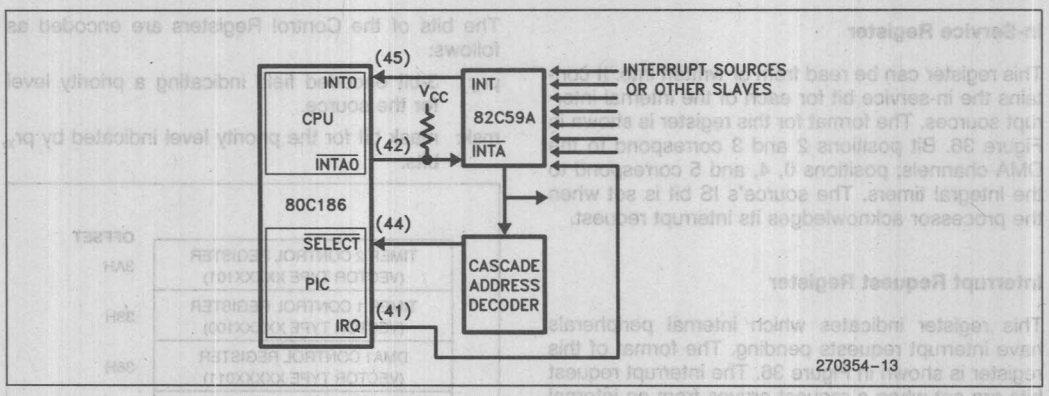


Figure 33. Slave Mode Interrupt Controller Connections

Correct master-slave interface requires decoding of the slave addresses (CAS0-2). Slave 82C59As do this internally. Because of pin limitations, the 80C186 slave address will have to be decoded externally. $\overline{\text{SELECT}}$ (Pin 44) is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{\text{INTA0}}$ (Pin 42) is used as an acknowledge output, suitable to drive the $\overline{\text{INTA}}$ input of an 82C59A.

Interrupt Nesting

Slave Mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the Slave Mode

Vector generation in Slave Mode is exactly like that of an 8259A or 82C59A slave. The interrupt controller generates an 8-bit vector type number which the CPU multiplies by four to use as an address into the vector table. The five most significant bits of this type number are user-programmable while the three least significant bits are defined according to Figure 34. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In Slave Mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the Slave Mode

All control and command registers are located inside the internal peripheral control block. Figure 34 shows the offsets of these registers.

End-of-Interrupt Register

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 35. It initiates an EOI command when written by the 80C186 CPU.

The bits in the EOI register are encoded as follows:

VT_X: Three least-significant vector type bits corresponding to the source for which the IS bit is to be reset. Figure 34 indicates these bits.

In-Service Register

This register can be read from or written into. It contains the in-service bit for each of the internal interrupt sources. The format for this register is shown in Figure 36. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

Interrupt Request Register

This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 36. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request. As in Master Mode, D0 and D1 are read/write; all other bits are read only.

Mask Register

This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 36. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

Control Registers

These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 37. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source.

msk: mask bit for the priority level indicated by pr_x bits.

	OFFSET
TIMER 2 CONTROL REGISTER (VECTOR TYPE XXXXX101)	3AH
TIMER 1 CONTROL REGISTER (VECTOR TYPE XXXXX100)	38H
DMA1 CONTROL REGISTER (VECTOR TYPE XXXXX011)	36H
DMA0 CONTROL REGISTER (VECTOR TYPE XXXXX010)	34H
TIMER0 CONTROL REGISTER (VECTOR TYPE XXXXX000)	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT-REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY-LEVEL MASK REGISTER	2AH
MASK REGISTER	28H
SPECIFIC EOI REGISTER	22H
INTERRUPT VECTOR REGISTER	20H

Figure 34. Interrupt Controller Registers (Slave Mode)

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0	•	•	•	•	0	0	0	0	0	0	VT2	VT1	VT0

Figure 35. Specific EOI Register Format

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0	•	•	•	•	0	0	0	TMR2	TMR1	D1	D0	0	TMR0

Figure 36. In-Service, Interrupt Request, and Mask Register Format

Interrupt Vector Register

This register provides the upper five bits of the interrupt vector address. The format of this register is shown in Figure 38. The interrupt controller itself provides the lower three bits of the interrupt vector as determined by the priority level of the interrupt request.

The format of the bits in this register is:

t_x: 5-bit field indicating the upper five bits of the vector address.

Priority-Level Mask Register

This register indicates the lowest priority-level interrupt which will be serviced.

The encoding of the bits in this register is:

m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

Interrupt Status Register

This register is defined as in Master Mode except that DHLT is not implemented (see Figure 27).

Interrupt Controller and Reset

Upon RESET, the interrupt controller will perform the following actions:

- All SFNM bits reset to 0, implying Fully Nested Mode.
- All PR bits in the various control registers set to 1. This places all sources at lowest priority (level 111).
- All LTM bits reset to 0, resulting in edge-sense mode.
- All Interrupt Service bits reset to 0.
- All Interrupt Request bits reset to 0.
- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-Cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to Master Mode.

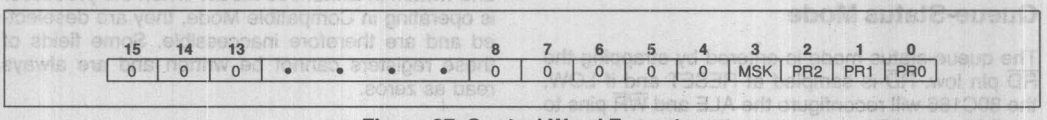


Figure 37. Control Word Format

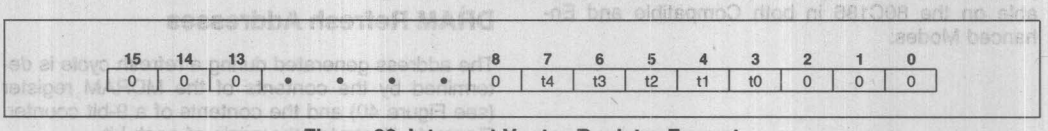


Figure 38. Interrupt Vector Register Format

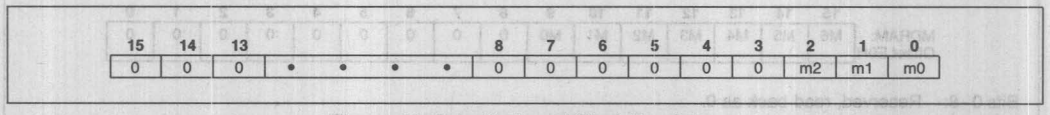


Figure 39. Priority Level Mask Register

Enhanced Mode Operation

In Compatible Mode the 80C186 operates with all the features of the NMOS 80186, with the exception of 8087 support (i.e. no numeric coprocessing is possible in Compatible Mode). Queue-Status information is still available for design purposes other than 8087 support.

All the Enhanced Mode features are completely masked when in Compatible Mode. A write to any of the Enhanced Mode registers will have no effect, while a read will not return any valid data.

In Enhanced Mode, the 80C186 will operate with Power-Save, DRAM refresh, and numerics coprocessor support in addition to all the Compatible Mode features.

Entering Enhanced Mode

If connected to a numerics coprocessor, this mode will be invoked automatically. Without an NPX, this mode can be entered by tying the RESET output signal from the 80C186 to the TEST/BUSY input.

Queue-Status Mode

The queue-status mode is entered by strapping the $\overline{RD}$ pin low. $\overline{RD}$ is sampled at RESET and if LOW, the 80C186 will reconfigure the ALE and $\overline{WR}$ pins to be QS0 and QS1 respectively. This mode is available on the 80C186 in both Compatible and Enhanced Modes.

DRAM Refresh Control Unit Description

The Refresh Control Unit (RCU) automatically generates DRAM refresh bus cycles. The RCU operates only in Enhanced Mode. After a programmable period of time, the RCU generates a memory read request to the BIU. If the address generated during a refresh bus cycle is within the range of a properly programmed chip select, that chip select will be activated when the BIU executes the refresh bus cycle. The ready logic and wait states programmed for that region will also be in force. If no chip select is activated, then external ready is automatically required to terminate the refresh bus cycle.

If the HLDA pin is active when a DRAM refresh request is generated (indicating a bus hold condition), then the 80C186 will deactivate the HLDA pin in order to perform a refresh cycle. The circuit external to the 80C186 must remove the HOLD signal for at least one clock in order to execute the refresh cycle. The sequence of HLDA going inactive while HOLD is being held active can be used to signal a pending refresh request.

All registers controlling DRAM refresh may be read and written in Enhanced Mode. When the processor is operating in Compatible Mode, they are deselected and are therefore inaccessible. Some fields of these registers cannot be written and are always read as zeros.

DRAM Refresh Addresses

The address generated during a refresh cycle is determined by the contents of the MDRAM register (see Figure 40) and the contents of a 9-bit counter. Figure 41 illustrates the origin of each bit.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MDRAM: Offset E0H	M6	M5	M4	M3	M2	M1	M0	0	0	0	0	0	0	0	0	0

Bits 0–8: Reserved, read back as 0.

Bits 9–15: M0–M6, are address bits A13–A19 of the 20-bit memory refresh address. These bits should correspond to any chip select address to be activated for the DRAM partition. These bits are cleared to 0 on RESET.

Figure 40. Memory Partition Register

A19	A18	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0
M6	M5	M4	M3	M2	M1	M0	0	0	0	CA8	CA7	CA6	CA5	CA4	CA3	CA2	CA1	CA0	1

M6–M0: Bits defined by MDRAM Register

CA8–CA0: Bits defined by refresh address counter. These bits change according to a linear/feedback shift register; they do not directly follow a binary count.

Figure 41. Addresses Generated by RCU

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CDRAM: Offset E2H	0	0	0	0	0	0	0	C8	C7	C6	C5	C4	C3	C2	C1	C0

Bits 0–8: C0–C8, clock divisor register, holds the number of CLKOUT cycles between each refresh request.

Bits 9–15: Reserved, read back as 0.

Figure 42. Clock Pre-Scaler Register

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDRAM: Offset E4H	E	0	0	0	0	0	0	T8	T7	T6	T5	T4	T3	T2	T1	T0

Bits 0–8: T0–T8, refresh clock counter outputs. Read only.

Bits 9–14: Reserved, read back as 0.

Bit 15: Enable RCU, set to 0 on RESET.

Figure 43. Enable RCU Register

Refresh Control Unit Programming and Operation

After programming the MDRAM and the CDRAM registers (Figures 40 and 42), the RCU is enabled by setting the "E" bit in the EDRAM register (Figure 43). The clock counter (T0–T8 of EDRAM) will be loaded from C0–C8 of CDRAM during T_3 of instruction cycle that sets the "E" bit. The clock counter is then decremented at each subsequent CLKOUT.

A refresh is requested when the value of the counter has reached 1 and the counter is reloaded from CDRAM. In order to avoid missing refresh requests, the value in the CDRAM register should always be at least 18 (12H). Clearing the "E" bit at anytime will clear the counter and stop refresh requests, but will not reset the refresh address counter.

POWER-SAVE CONTROL

Power Save Operation

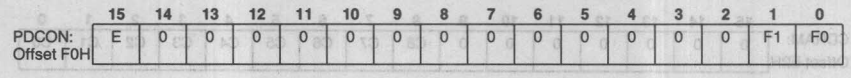
The 80C186, when in Enhanced Mode, can enter a power saving state by internally dividing the processor clock frequency by a programmable factor. This divided frequency is also available at the CLKOUT pin. The PDCON register contains the two-bit fields for selecting the clock division factor and the enable bit.

All internal logic, including the Refresh Control Unit and the timers, will have their clocks slowed down by the division factor. To maintain a real time count or a fixed DRAM refresh rate, these peripherals must be re-programmed when entering and leaving the power-save mode.

The power-save mode is exited whenever an interrupt is processed by automatically resetting the enable bit. If the power-save mode is to be re-entered after serving the interrupt, the enable bit will need to be set in software before returning from the interrupt routine.

The internal clocks of the 80C186 will begin to be divided during the T_3 state of the instruction cycle that sets the enable bit. Clearing the enable bit will restore full speed in the T_3 state of that instruction.

At no time should the internal clock frequency be allowed to fall below 0.5 MHz. This is the minimum operational frequency of the 80C186. For example, an 80C186 running with a 12 MHz crystal (6 MHz CLOCKOUT) should never have a clock divisor greater than eight.



Bits 0–1: Clock Divisor Select

F1	F0	Division Factor
0	0	divide by 1
0	1	divide by 4
1	0	divide by 8
1	1	divide by 16

Bits 2–14: Reserved, read back as zero.
Bit 15: Enable Power Save Mode. Set to zero on RESET.

Figure 44. Power-Save Control Register

Interface for 80C187 Numeric Processor Extension

In Enhanced Mode, three of the mid-range memory chip selects are redefined according to Table 16 for use with the 80C187. The fourth chip select, $\overline{MCS2}$ functions as in compatible mode, and may be programmed for activity with ready logic and wait states accordingly. As in compatible mode, $\overline{MCS2}$ will function for one-fourth a programmed block size.

Table 16. $\overline{MCS}$ Assignments

Compatible Mode	Enhanced Mode	
$\overline{MCS0}$	PEREQ	Processor Extension Request
$\overline{MCS1}$	$\overline{ERROR}$	NPX Error
$\overline{MCS2}$	$\overline{MCS2}$	Mid-Range Chip Select
$\overline{MCS3}$	$\overline{NPS}$	Numeric Processor Select

Four port addresses are assigned to the 80C186/80C187 interface for 16-bit reads and writes. Table 17 shows the port definitions. These ports are not accessible by using the 80C186 I/O instructions. However, numerics operations will cause a $\overline{PCS}$ line to be activated if it is properly programmed for this I/O range.

Table 17. Numerics Coprocessor I/O Port Assignments

I/O Address	Read Definition	Write Definition
00F8H	Status/Control	Opcode
00FAH	Data	Data
00FCH	reserved	CS:IP, DS:EA
00FEH	Opcode Status	reserved

ONCE™ Test Mode

To facilitate testing and inspection of devices when fixed into a target system, the 80C186 has a test mode available which allows all pins to be placed in a high-impedance state. ONCE stands for "ON Circuit Emulation". When placed in this mode, the 80C186 will put all pins in the high-impedance state until RESET.

The $\overline{ONCE}$ mode is selected by tying the $\overline{UCS}$ and the $\overline{LCS}$ LOW during RESET. These pins are sampled on the low-to-high transition of the $\overline{RES}$ pin. The $\overline{UCS}$ and the $\overline{LCS}$ pins have weak internal pull-up resistors similar to the $\overline{RD}$ and $\overline{TEST}$/BUSY pins to guarantee normal operation.

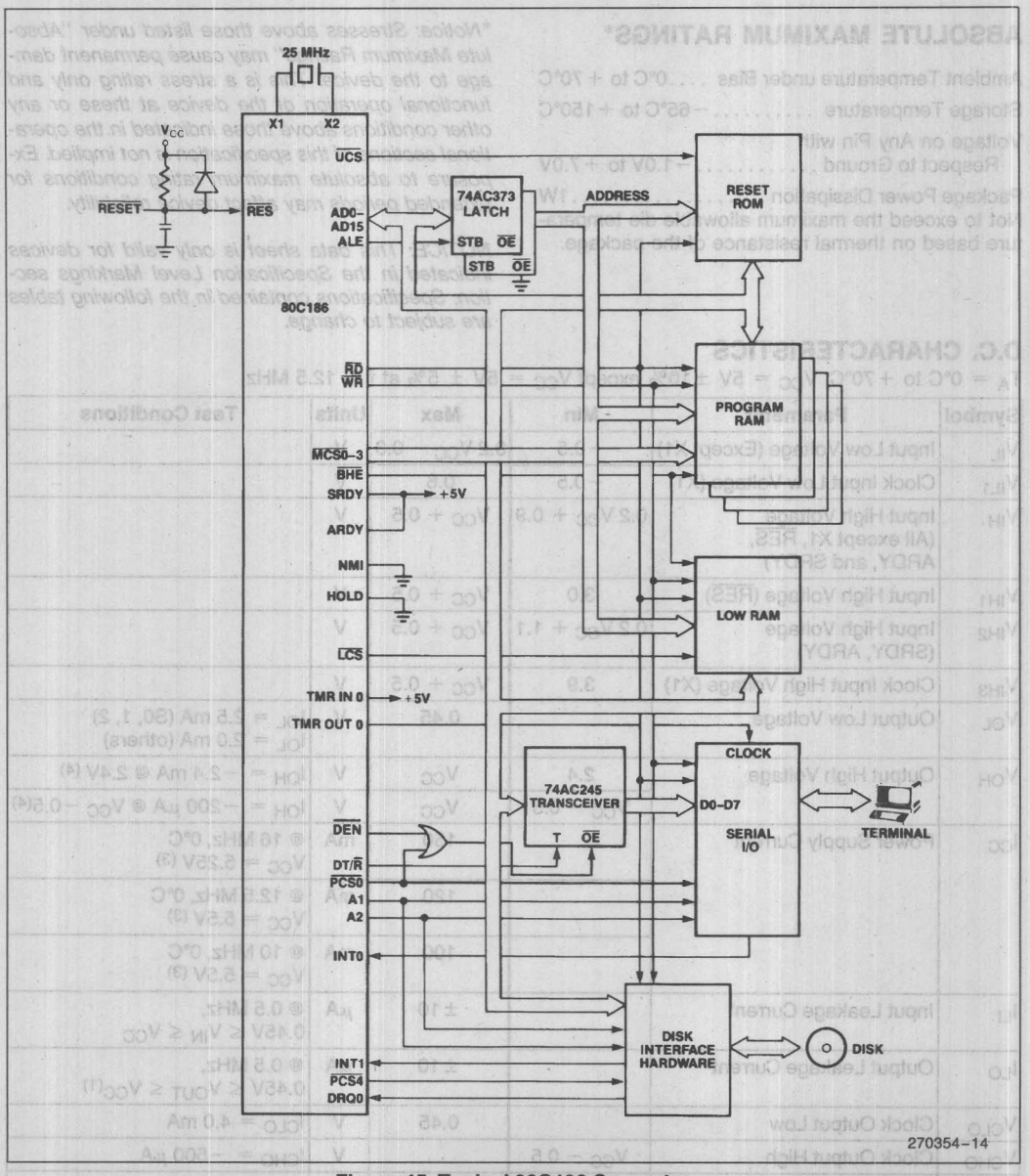


Figure 45. Typical 80C186 Computer

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ....0°C to +70°C

Storage Temperature .....−65°C to +150°C

Voltage on Any Pin with Respect to Ground .....−1.0V to +7.0V

Package Power Dissipation 1W
Not to exceed the maximum allowable die temperature based on thermal resistance of the package.

**Notice: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

NOTICE: This data sheet is only valid for devices indicated in the Specification Level Markings section. Specifications contained in the following tables are subject to change.

D.C. CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = 5V ±10% except V_{CC} = 5V ± 5% at f > 12.5 MHz

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage (Except X1)	−0.5	0.2 V_{CC} − 0.3	V	
V_{IL1}	Clock Input Low Voltage (X1)	−0.5	0.6	V	
V_{IH}	Input High Voltage (All except X1, $\overline{RES}$, ARDY, and SRDY)	0.2 V_{CC} + 0.9	V_{CC} + 0.5	V	
V_{IH1}	Input High Voltage ($\overline{RES}$)	3.0	V_{CC} + 0.5	V	
V_{IH2}	Input High Voltage (SRDY, ARDY)	0.2 V_{CC} + 1.1	V_{CC} + 0.5	V	
V_{IH3}	Clock Input High Voltage (X1)	3.9	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.5 mA (S0, 1, 2) I_{OL} = 2.0 mA (others)
V_{OH}	Output High Voltage	2.4	V_{CC}	V	I_{OH} = −2.4 mA @ 2.4V (4)
		V_{CC} − 0.5	V_{CC}	V	I_{OH} = −200 μA @ V_{CC} −0.5(4)
I_{CC}	Power Supply Current		150	mA	@ 16 MHz, 0°C V_{CC} = 5.25V (3)
			120	mA	@ 12.5 MHz, 0°C V_{CC} = 5.5V (3)
			100	mA	@ 10 MHz, 0°C V_{CC} = 5.5V (3)
I_{LI}	Input Leakage Current		±10	μA	@ 0.5 MHz, 0.45V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±10	μA	@ 0.5 MHz, 0.45V ≤ V_{OUT} ≤ V_{CC}(1)
V_{CLO}	Clock Output Low		0.45	V	I_{CLO} = 4.0 mA
V_{CHO}	Clock Output High	V_{CC} − 0.5		V	I_{CHO} = −500 μA
C_{IN}	Input Capacitance		10	pF	@ 1 MHz(2)
C_{IO}	Output or I/O Capacitance		20	pF	@ 1 MHz(2)

NOTES:
1. Pins being floated during HOLD or by invoking the ONCE Mode.
2. Characterization conditions are a) Frequency = 1 MHz; b) Unmeasured pins at GND; c) V_{IN} at + 5.0V or 0.45V. This parameter is not tested.
3. Current is measured with the device in RESET with X1 and X2 driven and all other non-power pins open.
4. $\overline{RD}$/QSMD, $\overline{UCS}$, $\overline{LCS}$, $\overline{MCS0}$/PEREQ, $\overline{MCS1}$/$\overline{ERROR}$, and $\overline{TEST}$/BUSY pins have internal pullup devices. Loading some of these pins above I_{OH} = −200 μA can cause the 80C186 to go into alternative modes of operation. See the section on Local Bus Controller and Reset for details.

POWER SUPPLY CURRENT

Current is linearly proportional to clock frequency and is measured with the device in RESET with X1 and X2 driven and all other non-power pins open.

Maximum current is given by I_{CC} = 8.4 mA × freq. (MHz) + 15 mA.

Typical current is given by I_{CC} (typical) = 6.4 mA × freq. (MHz) + 4.0 mA. "Typicals" are based on a limited number of samples taken from early manufacturing lots measured at V_{CC} = 5V and room temperature. "Typicals" are not guaranteed.

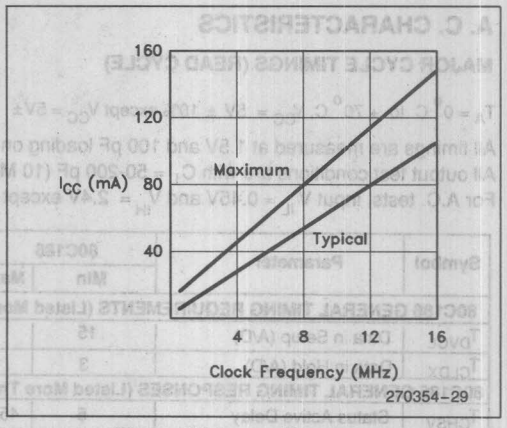


Figure 46. I_{CC} vs Frequency

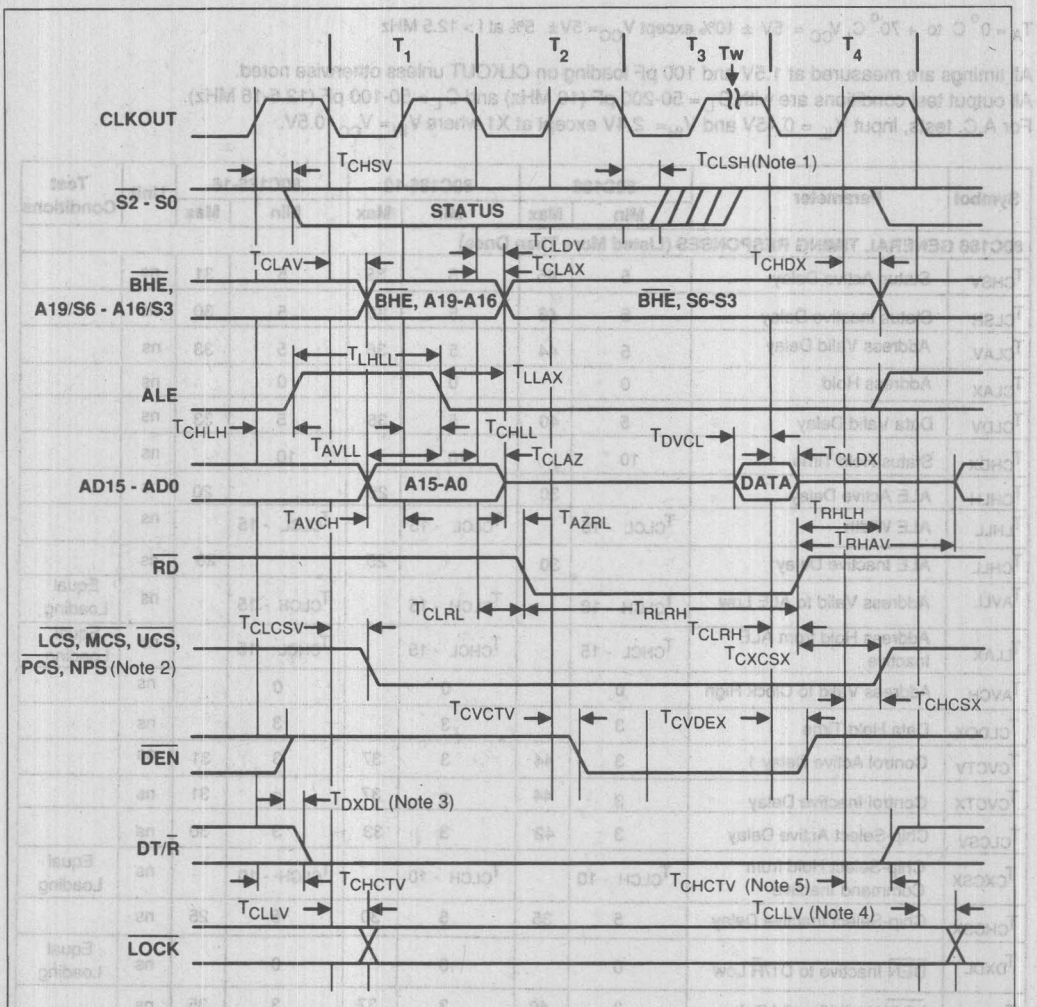
1

T_{CLDX}	Data in Hold (A/D)	3		3		3		ns	
80C186 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	T_{CLCH} - 18		T_{CLCH} - 15		T_{CLCH} - 15		ns	Equal Loading
T_{LLAX}	Address Hold from ALE Inactive	T_{CHCL} - 15		T_{CHCL} - 15		T_{CHCL} - 15		ns	Equal Loading
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CLCSV}	Chip-Select Active Delay	3	42	3	33	3	30	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	T_{CLCH} - 10		T_{CLCH} - 10		T_{CLCH} - 10		ns	Equal Loading
T_{CHCSX}	Chip-Select Inactive Delay	5	35	5	30	5	25	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVDEX}	$\overline{DEN}$ Inctive Delay	5	44	5	37	5	31	ns	
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	
80C186 TIMING RESPONSES (Read Cycle)									
T_{AZRL}	Address Float to $\overline{RD}$ Active	0		0		0		ns	
T_{CLRL}	$\overline{RD}$ Active Delay	5	44	5	37	5	31	ns	
T_{RLRH}	$\overline{RD}$ Pulse Width	$2T_{CLCL}$ - 30		$2T_{CLCL}$ - 25		$2T_{CLCL}$ - 25		ns	
T_{CLRH}	$\overline{RD}$ Inactive Delay	5	44	5	37	5	31	ns	
T_{RHLH}	$\overline{RD}$ Inactive to ALE High	T_{CLCH} - 14		T_{CLCH} - 14		T_{CLCH} - 14		ns	Equal Loading
T_{RHAV}	$\overline{RD}$ Inactive to Address Active	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	Equal Loading

270354-34

A. C. CHARACTERISTICS

READ CYCLE WAVEFORMS



NOTES:

1. Status inactive in state preceding T_4.
3. For write cycle followed by read cycle.
4. T_1 of next bus cycle.
5. Changes in T-state preceding next bus cycle if followed by write.

270354-35

A. C. CHARACTERISTICS

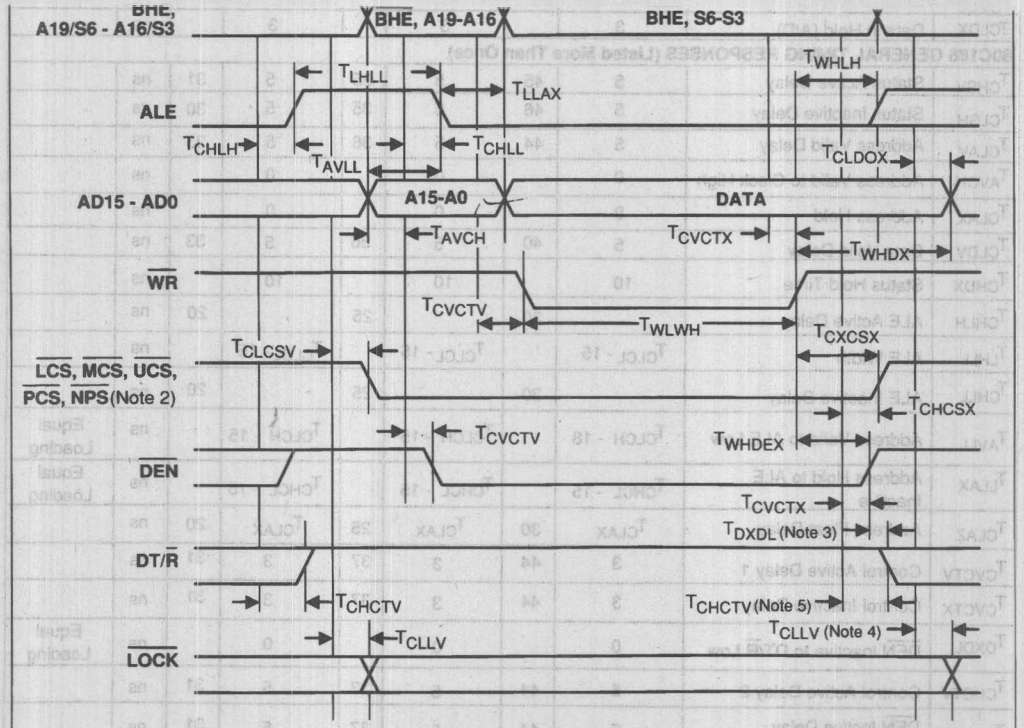
MAJOR CYCLE TIMINGS (WRITE CYCLE)

$T_A = 0^\circ C$ to $+70^\circ C$, V_{CC} = 5V ± 10% except V_{CC} = 5V± 5% at f > 12.5 MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C186		80C186-12		80C186-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C186 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	T_{CLCH} - 18		T_{CLCH} - 15		T_{CLCH} - 15		ns	Equal Loading
T_{LLAX}	Address Hold from ALE Inactive	T_{CHCL} - 15		T_{CHCL} - 15		T_{CHCL} - 15		ns	Equal Loading
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLDOX}	Data Hold Time	3		3		3		ns	
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVCTX}	Control Inactive Delay	3	44	3	37	3	31	ns	
T_{CLCSV}	Chip-Select Active Delay	3	42	3	33	3	30	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	T_{CLCH} - 10		T_{CLCH} - 10		T_{CLCH} - 10		ns	Equal Loading
T_{CHCSX}	Chip-Select Inactive Delay	5	35	5	30	5	25	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	
80C186 TIMING RESPONSES (Write Cycle)									
T_{WLWH}	$\overline{WR}$ Pulse Width	$2T_{CLCL}$ - 30		$2T_{CLCL}$ - 25		$2T_{CLCL}$ - 25		ns	
T_{WHLH}	$\overline{WR}$ Inactive to ALE High	T_{CLCH} - 14		T_{CLCH} - 14		T_{CLCH} - 14		ns	Equal Loading
T_{WHDX}	Data Hold After $\overline{WR}$	T_{CLCL} - 34		T_{CLCL} - 20		T_{CLCL} - 20		ns	Equal Loading
T_{WHDEX}	$\overline{WR}$ Inactive to $\overline{DEN}$ Inactive	T_{CLCH} - 10		T_{CLCH} - 10		T_{CLCH} - 10		ns	Equal Loading

270354-36



NOTES:

1. Status inactive in state preceding T_4.
2. If latched A_1 and A_2 are selected instead of $\overline{PCS5}$ and $\overline{PCS6}$, only T_{CLCSV} is applicable.
3. For write cycle followed by read cycle.
4. T_1 of next bus cycle.
5. Changes in T-state preceding next bus cycle if followed by read, INTA, or halt.

270354-37

A. C. CHARACTERISTICS

MAJOR CYCLE TIMINGS (INTERRUPT ACKNOWLEDGE CYCLE)

$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

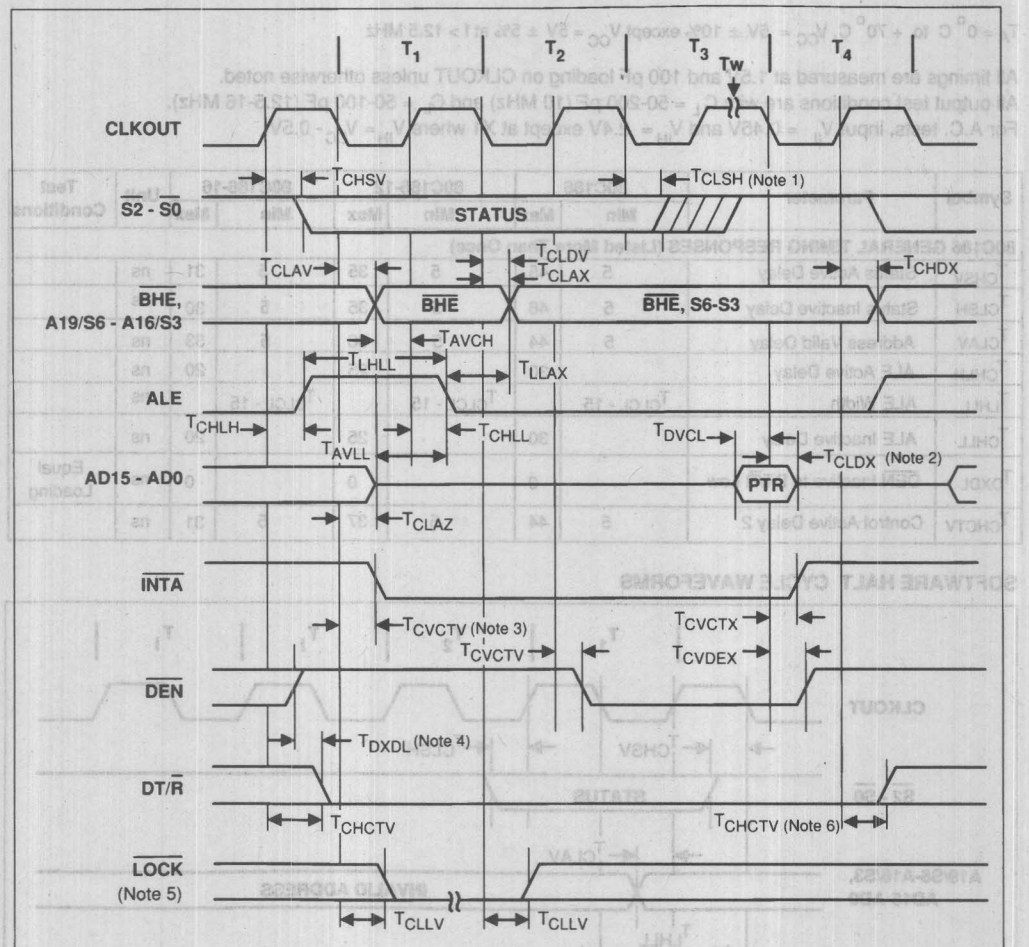
All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C186		80C186-12		80C186-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C186 GENERAL TIMING REQUIREMENTS (Listed More Than Once)									
T_{DVCL}	Data in Setup (A/D)	15		15		15		ns	
TCLDX	Data in Hold (A/D)	3		3		3		ns	
80C186 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	T_{CLCH} - 18		T_{CLCH} - 15		T_{CLCH} - 15		ns	Equal Loading
T_{LLAX}	Address Hold to ALE Inactive	T_{CHCL} - 15		T_{CHCL} - 15		T_{CHCL} - 15		ns	Equal Loading
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVCTX}	Control Inactive Delay	3	44	3	37	3	31	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	
T_{CVDEX}	$\overline{DEN}$ Inctive Delay (Non-Write Cycles)	5	44	5	37	5	31	ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	

270354-38

A. C. CHARACTERISTICS

INTERRUPT ACKNOWLEDGE CYCLE WAVEFORMS



NOTES:

1. Status inactive in state preceding T_4.
2. The data hold time lasts only until $\overline{INTA}$ goes inactive, even if the $\overline{INTA}$ transition occurs prior to T_{CLDX} (min).
3. $\overline{INTA}$ occurs one clock later in Slave Mode.
4. For write cycle followed by interrupt acknowledge cycle.
5. $\overline{LOCK}$ is active upon T_1 of the first interrupt acknowledge cycle and inactive upon T_2 of the second interrupt acknowledge cycle.

270354-39

A. C. CHARACTERISTICS

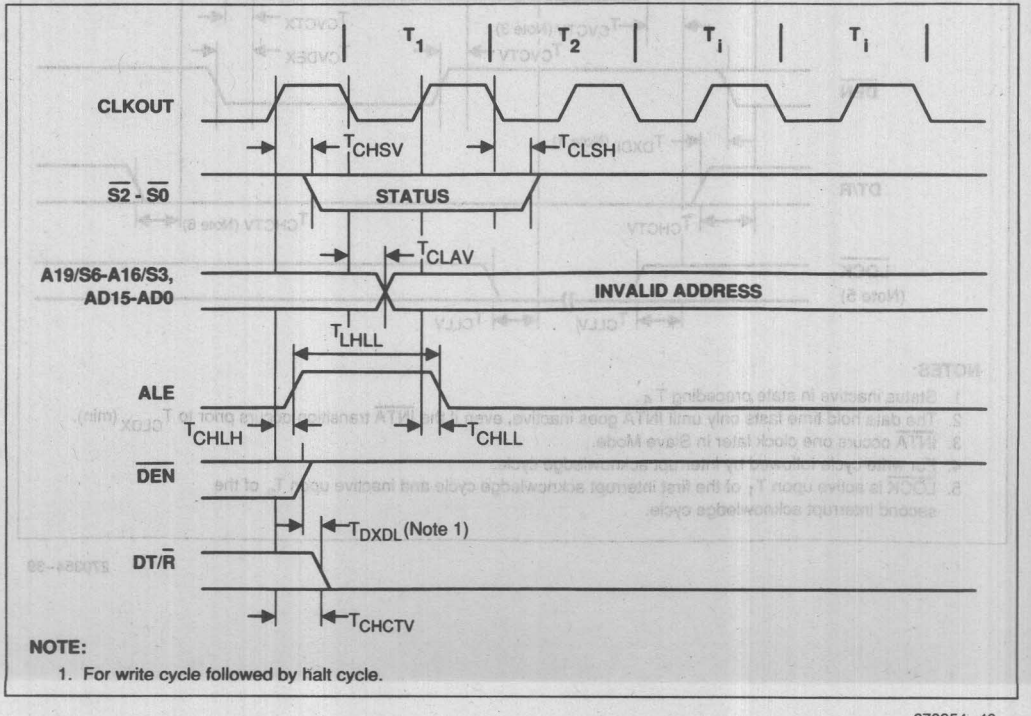
SOFTWARE HALT CYCLE TIMINGS

$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with $C_L = 50\text{-}200$ pF (10 MHz) and $C_L = 50\text{-}100$ pF (12.5-16 MHz).
For A.C. tests, input $V_{IL} = 0.45V$ and $V_{IH} = 2.4V$ except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C186		80C186-12		80C186-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C186 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	$T_{CLCL} - 15$		$T_{CLCL} - 15$		$T_{CLCL} - 15$		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low		0		0		0	ns	Equal Loading
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	

SOFTWARE HALT CYCLE WAVEFORMS



NOTE:
1. For write cycle followed by halt cycle.

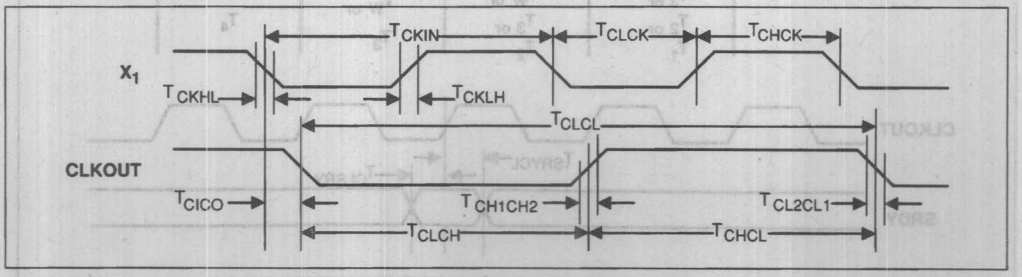
270354-40

T_{CLCK}	CLKIN Low Time	20		16		13		ns	1.5 V(2)
T_{CHCK}	CLKIN High Time	20		16		13		ns	1.5 V(2)
T_{CKHL}	CLKIN Fall Time		5		5		5	ns	3.5 to 1.0V
T_{CKLH}	CLKIN Rise Time		5		5		5	ns	1.0 to 3.5V
80C186 CLKOUT TIMING									
T_{CICO}	CLKIN to CLKOUT Skew		25		21		17	ns	
T_{CLCL}	CLKOUT Period	100	2000	80	2000	62.5	2000	ns	
T_{CLCH}	CLKOUT Low Time	0.5 T_{CLCL} -8		0.5 T_{CLCL} -7		0.5 T_{CLCL} -7		ns	C_L=100pF(2)
		0.5 T_{CLCL} -6		0.5 T_{CLCL} -5		0.5 T_{CLCL} -5		ns	C_L=50pF(3)
T_{CHCL}	CLKOUT High Time	0.5 T_{CLCL} -8		0.5 T_{CLCL} -7		0.5 T_{CLCL} -7		ns	C_L=100pF(4)
		0.5 T_{CLCL} -6		0.5 T_{CLCL} -5		0.5 T_{CLCL} -5		ns	C_L=50pF(3)
T_{CH1CH2}	CLKOUT Rise Time		10		10		10	ns	1.0 to 3.5V
T_{CL2CL1}	CLKOUT Fall Time		10		10		10	ns	3.5 to 1.0V

NOTES:

1. T_{CLCK} and T_{CHCK} (CLKIN Low and High times) should not have a duration less than 40% of T_{CKIN}
2. Tested under worst case conditions: V_{CC} = 5.5V (5.25V @ 16 MHz). T_A = 70° C.
3. Not Tested.
4. Tested under worst case conditions: V_{CC} = 4.5V (4.75V @ 16 MHz). T_A = 0° C.

CLOCK WAVEFORMS



270354-41

A. C. CHARACTERISTICS

READY, PERIPHERAL, AND QUEUE STATUS TIMINGS

$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

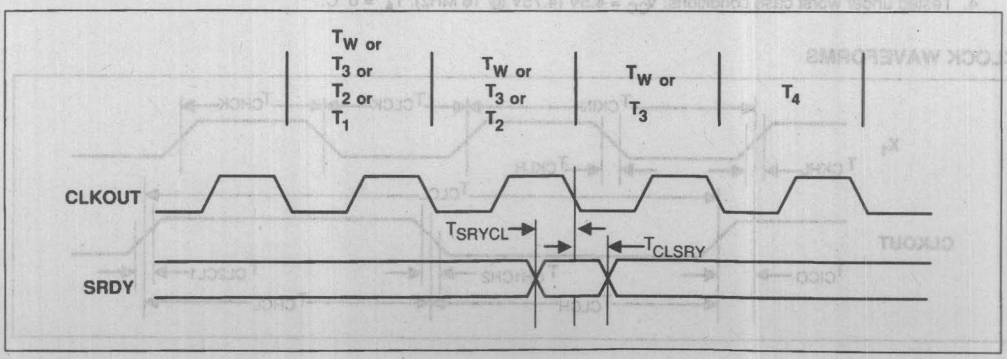
All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C186		80C186-12		80C186-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C186 READY AND PERIPHERAL TIMING REQUIREMENTS									
T_{SRYCL}	Synchronous Ready(SRDY) Transition Setup Time (1)	15		15		15		ns	
T_{CLSRY}	SRDY Transition Hold Time (1)	15		15		15		ns	
T_{ARYCH}	ARDY Resolution Transition Setup Time (2)	15		15		15		ns	
T_{CLARX}	ARDY Active Hold Time (1)	15		15		15		ns	
T_{ARYCHL}	ARDY Inactive Holding Time	15		15		15		ns	
T_{ARYLCL}	Asynchronous Ready (ARDY) Setup Time (1)	25		25		25		ns	
T_{INVCH}	INTx, NMI, $\overline{TEST}$/BUSY, TMR IN Setup Time (2)	15		15		15		ns	
T_{INVCL}	DRQ0, DRQ1 Setup Time (2)	15		15		15		ns	
80C186 PERIPHERAL AND QUEUE STATUS TIMING RESPONSES									
T_{CLTMV}	Timer Output Delay		40		33		27	ns	
T_{CHQSV}	Queue Status Delay		37		32		30	ns	

NOTES:

1. To guarantee proper operation.
2. To guarantee recognition at clock edge.

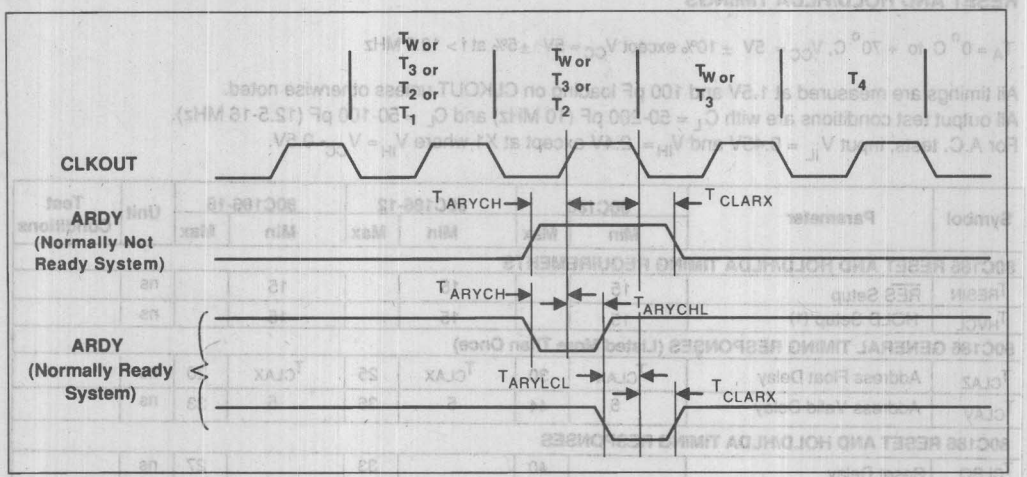
SYNCHRONOUS READY (SRDY) WAVEFORMS



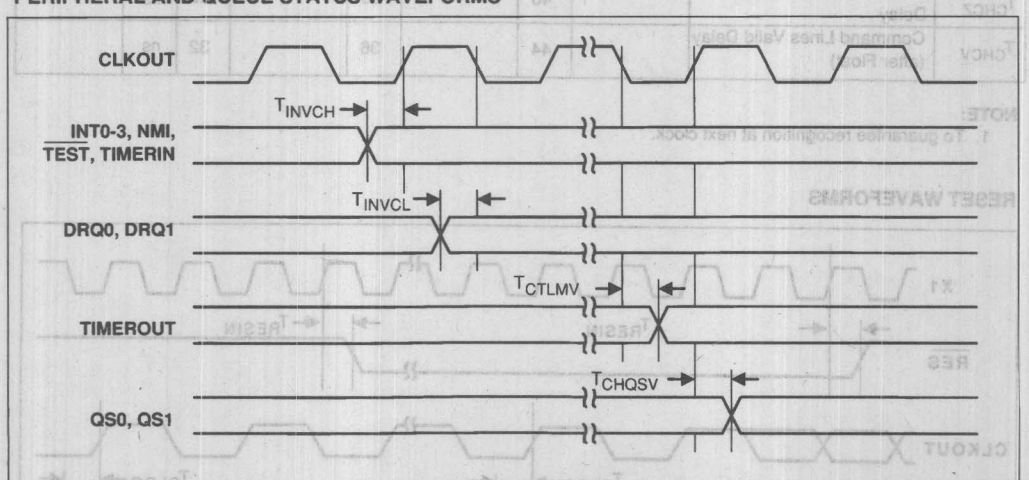
270354-42

A. C. CHARACTERISTICS

ASYNCHRONOUS READY (ARDY) WAVEFORMS



PERIPHERAL AND QUEUE STATUS WAVEFORMS



270354-43

A. C. CHARACTERISTICS

RESET AND HOLD/HLDA TIMINGS

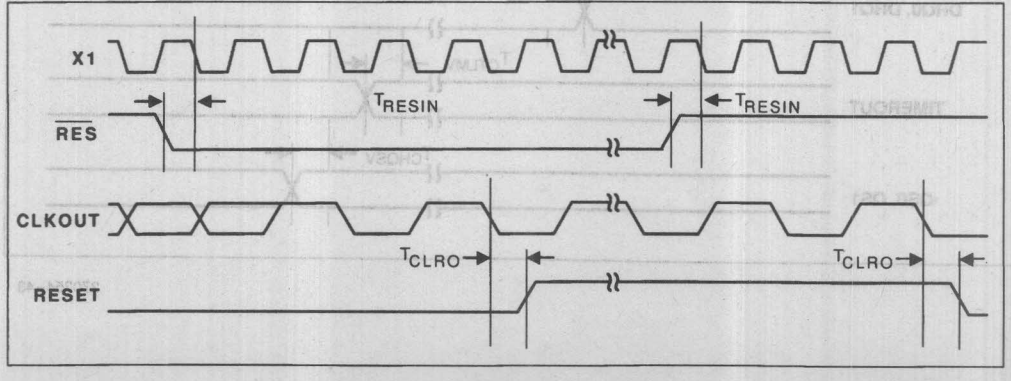
$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C186		80C186-12		80C186-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C186 RESET AND HOLD/HLDA TIMING REQUIREMENTS									
T_{RESIN}	$\overline{RES}$ Setup	15		15		15		ns	
T_{HVCL}	HOLD Setup (1)	15		15		15		ns	
80C186 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
80C186 RESET AND HOLD/HLDA TIMING RESPONSES									
T_{CLRO}	Reset Delay		40		33		27	ns	
T_{CLHAV}	HLDA Valid Delay	3	40	3	33	3	25	ns	
T_{CHCZ}	Command Lines Float Delay		40		33		28	ns	
T_{CHCV}	Command Lines Valid Delay (after Float)		44		36		32	ns	

NOTE:
1. To guarantee recognition at next clock.

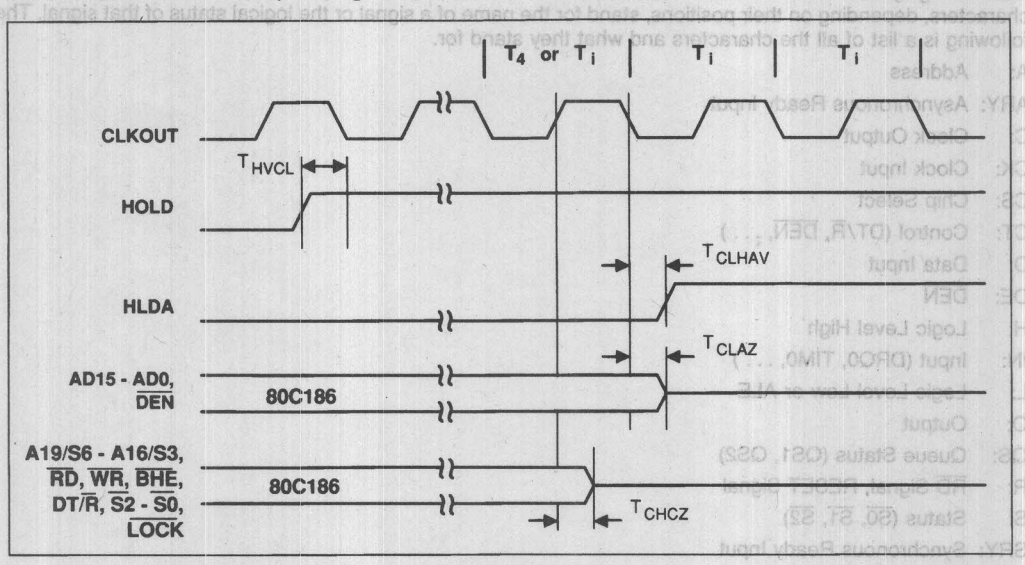
RESET WAVEFORMS



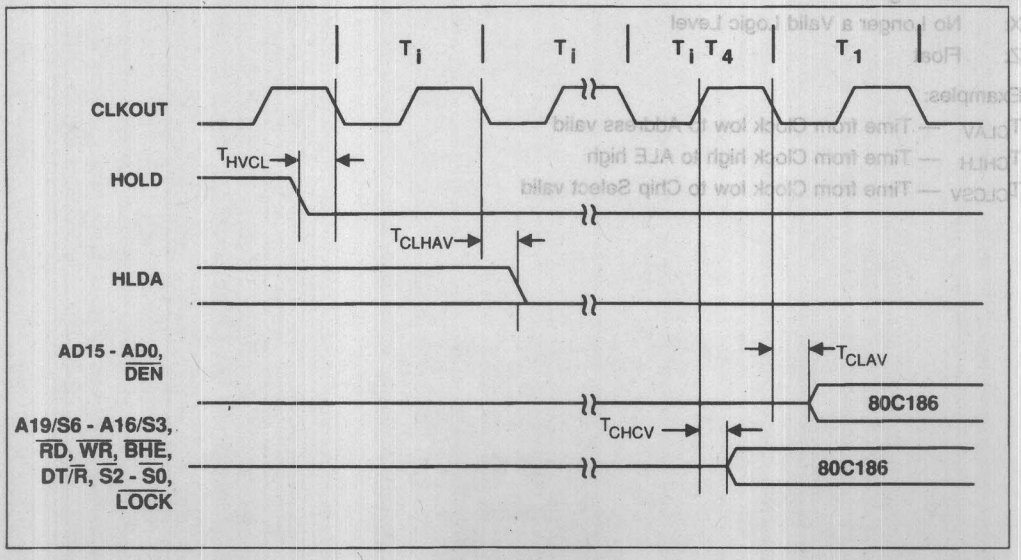
270354-44

A. C. CHARACTERISTICS

HOLD/HLDA WAVEFORMS (Entering Hold)

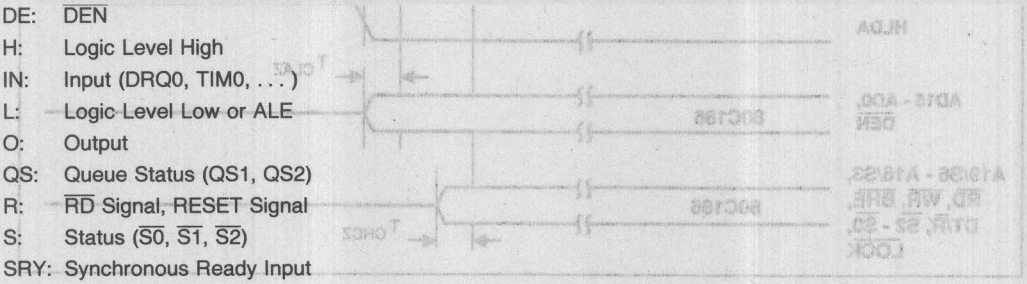


HOLD/HLDA WAVEFORMS (Leaving Hold)



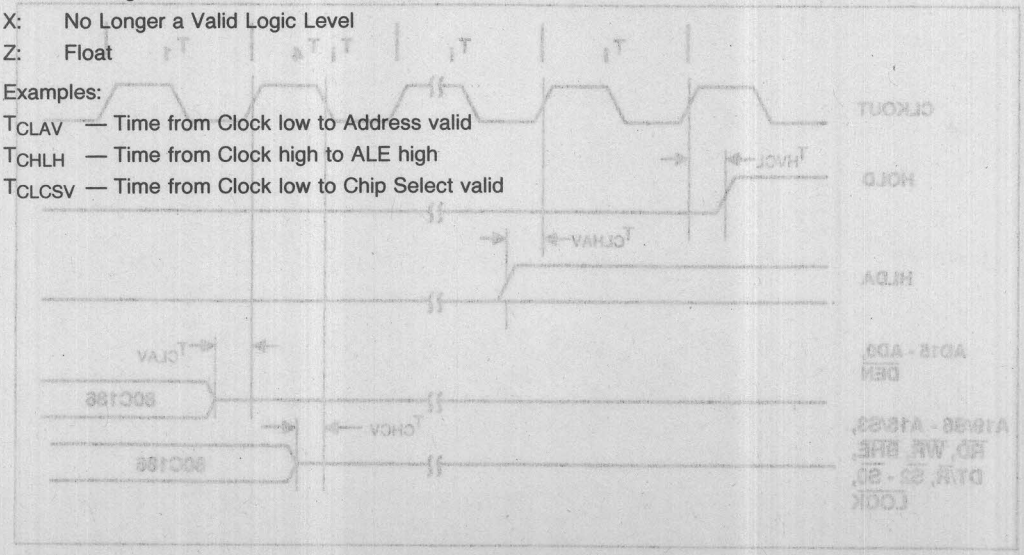
270354-45

DE: $\overline{DEN}$
H: Logic Level High
IN: Input (DRQ0, TIM0, . . .)
L: Logic Level Low or ALE
O: Output
QS: Queue Status (QS1, QS2)
R: $\overline{RD}$ Signal, RESET Signal
S: Status ($\overline{S0}$, $\overline{S1}$, $\overline{S2}$)
SRY: Synchronous Ready Input
V: Valid
W: WR Signal
X: No Longer a Valid Logic Level
Z: Float



Examples:

T_{CLAV} — Time from Clock low to Address valid
T_{CHLH} — Time from Clock high to ALE high
T_{CLCSV} — Time from Clock low to Chip Select valid



WAVEFORMS (Continued)

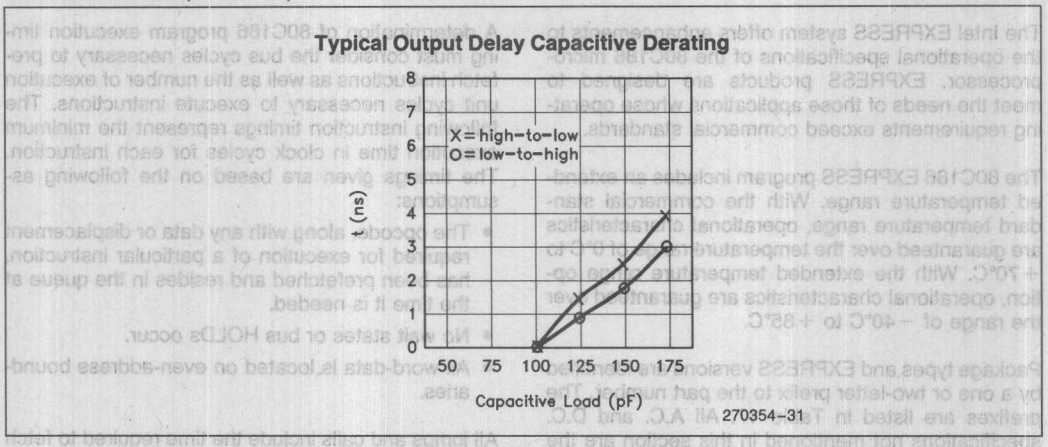


Figure 47. Capacitive Derating Curve

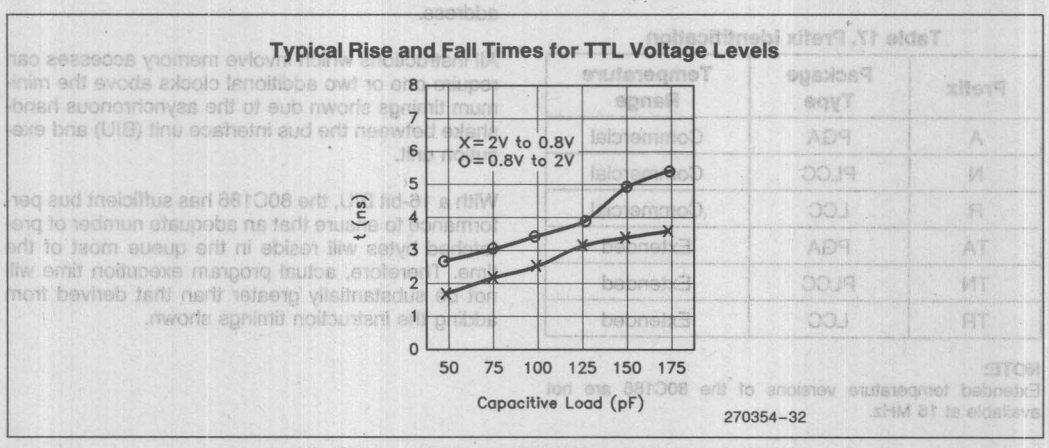


Figure 48. TTL Level Rise and Fall Times for Output Buffers

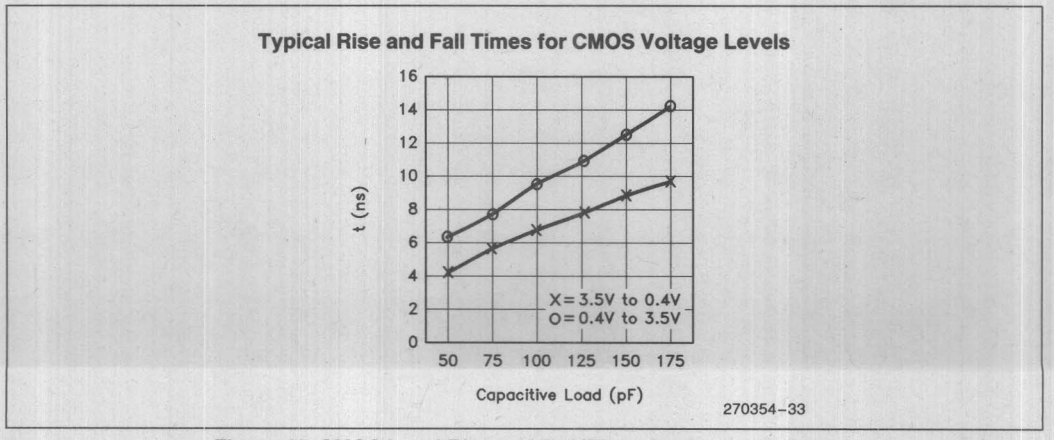


Figure 49. CMOS Level Rise and Fall Times for Output Buffers

80C186 EXPRESS

The Intel EXPRESS system offers enhancements to the operational specifications of the 80C186 microprocessor. EXPRESS products are designed to meet the needs of those applications whose operating requirements exceed commercial standards.

The 80C186 EXPRESS program includes an extended temperature range. With the commercial standard temperature range, operational characteristics are guaranteed over the temperature range of 0°C to +70°C. With the extended temperature range option, operational characteristics are guaranteed over the range of −40°C to +85°C.

Package types and EXPRESS versions are identified by a one or two-letter prefix to the part number. The prefixes are listed in Table 17. All A.C. and D.C. specifications not mentioned in this section are the same for both commercial and EXPRESS parts.

Table 17. Prefix Identification

Prefix	Package Type	Temperature Range
A	PGA	Commercial
N	PLCC	Commercial
R	LCC	Commercial
TA	PGA	Extended
TN	PLCC	Extended
TR	LCC	Extended

NOTE:
Extended temperature versions of the 80C186 are not available at 16 MHz.

80C186 EXECUTION TIMINGS

A determination of 80C186 program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDs occur.
- All word-data is located on even-address boundaries.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

All instructions which involve memory accesses can require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the bus interface unit (BIU) and execution unit.

With a 16-bit BIU, the 80C186 has sufficient bus performance to ensure that an adequate number of prefetched bytes will reside in the queue most of the time. Therefore, actual program execution time will not be substantially greater than that derived from adding the instruction timings shown.

INSTRUCTION SET SUMMARY

Function	Format				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1000100w	mod reg r/m			2/12	
Register/memory to register	1000101w	mod reg r/m			2/9	
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1	12–13	8/16-bit
Immediate to register	1011w reg	data	data if w=1		3–4	8/16-bit
Memory to accumulator	1010000w	addr-low	addr-high		8	
Accumulator to memory	1010001w	addr-low	addr-high		9	
Register/memory to segment register	10001110	mod 0 reg r/m			2/9	
Segment register to register/memory	10001100	mod 0 reg r/m			2/11	
PUSH = Push:						
Memory	11111111	mod 110 r/m			16	
Register	01010 reg				10	
Segment register	000reg110				9	
Immediate	011010s0	data	data if s=0		10	
PUSHA = Push All	01100000				36	
POP = Pop:						
Memory	10001111	mod 000 r/m			20	
Register	01011 reg				10	
Segment register	000reg111	(reg≠01)			8	
POPA = Pop All	01100001				51	
XCHG = Exchange:						
Register/memory with register	1000011w	mod reg r/m			4/17	
Register with accumulator	10010 reg				3	
IN = Input from:						
Fixed port	1110010w	port			10	
Variable port	1110110w				8	
OUT = Output to:						
Fixed port	1110011w	port			9	
Variable port	1110111w				7	
XLAT = Translate byte to AL	11010111				11	
LEA = Load EA to register	10001101	mod reg r/m			6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)		18	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)		18	
LAHF = Load AH with flags	10011111				2	
SAHF = Store AH into flags	10011110				3	
PUSHF = Push flags	10011100				9	
POPF = Pop flags	10011101				8	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
DATA TRANSFER (Continued)						
SEGMENT = Segment Override:						
CS	00101110				2	
SS	00110110				2	
DS	00111110				2	
ES	00100110				2	
ARITHMETIC						
ADD = Add:						
Reg/memory with register to either	000000dw	mod reg r/m			3/10	
Immediate to register/memory	100000sw	mod 000 r/m	data	data if s w = 01	4/16	
Immediate to accumulator	0000010w	data	data if w = 1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	000100dw	mod reg r/m			3/10	
Immediate to register/memory	100000sw	mod 010 r/m	data	data if s w = 01	4/16	
Immediate to accumulator	0001010w	data	data if w = 1		3/4	8/16-bit
INC = Increment:						
Register/memory	1111111w	mod 000 r/m			3/15	
Register	01000 reg				3	
SUB = Subtract:						
Reg/memory and register to either	001010dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 101 r/m	data	data if s w = 01	4/16	
Immediate from accumulator	0010110w	data	data if w = 1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	000110dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 011 r/m	data	data if s w = 01	4/16	
Immediate from accumulator	0001110w	data	data if w = 1		3/4	8/16-bit
DEC = Decrement						
Register/memory	1111111w	mod 001 r/m			3/15	
Register	01001 reg				3	
CMP = Compare:						
Register/memory with register	0011101w	mod reg r/m			3/10	
Register with register/memory	0011100w	mod reg r/m			3/10	
Immediate with register/memory	100000sw	mod 111 r/m	data	data if s w = 01	3/10	
Immediate with accumulator	0011110w	data	data if w = 1		3/4	8/16-bit
NEG = Change sign register/memory	1111011w	mod 011 r/m			3/10	
AAA = ASCII adjust for add	00110111				8	
DAA = Decimal adjust for add	00100111				4	
AAS = ASCII adjust for subtract	00111111				7	
DAS = Decimal adjust for subtract	00101111				4	
MUL = Multiply (unsigned):	1111011w	mod 100 r/m			3/10	
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
ARITHMETIC (Continued)			
IMUL = Integer multiply (signed):	1111011w | mod101 r/m		
Register-Byte		25–28	
Register-Word		34–37	
Memory-Byte		31–34	
Memory-Word		40–43	
IMUL = Integer Immediate multiply (signed)	011010s1 | mod reg r/m | data | data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1111011w | mod110 r/m		
Register-Byte		29	
Register-Word		38	
Memory-Byte		35	
Memory-Word		44	
IDIV = Integer divide (signed):	1111011w | mod111 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67	
AAM = ASCII adjust for multiply	11010100 | 00001010	19	
AAD = ASCII adjust for divide	11010101 | 00001010	15	
CBW = Convert byte to word	10011000	2	
CWD = Convert word to double word	10011001	4	
LOGIC **Shift/Rotate Instructions:**			
Register/Memory by 1	1101000w | mod TTT r/m	2/15	
Register/Memory by CL	1101001w | mod TTT r/m	5+n/17+n	
Register/Memory by Count	1100000w | mod TTT r/m | count	5+n/17+n	
	TTT Instruction 000 ROL 001 ROR 010 RCL 011 RCR 100 SHL/SAL 101 SHR 111 SAR		
AND = **And:**			
Reg/memory and register to either	001000dw | mod reg r/m	3/10	
Immediate to register/memory	1000000w | mod100 r/m | data | data if w=1	4/16	
Immediate to accumulator	0010010w | data | data if w=1	3/4	8/16-bit
TEST = **And function to flags, no result:**			
Register/memory and register	1000010w | mod reg r/m	3/10	
Immediate data and register/memory	1111011w | mod000 r/m | data | data if w=1	4/10	
Immediate data and accumulator	1010100w | data | data if w=1	3/4	8/16-bit
OR = **Or:**			
Reg/memory and register to either	000010dw | mod reg r/m	3/10	
Immediate to register/memory	1000000w | mod001 r/m | data | data if w=1	4/16	
Immediate to accumulator	0000110w | data | data if w=1	3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

CMPS = Compare byte/word	1010011w			22
SCAS = Scan byte/word	1010111w			15
LODS = Load byte/wd to AL/AX	1010110w			12
STOS = Store byte/wd from AL/AX	1010101w			10
INS = Input byte/wd from DX port	0110110w			14
OUTS = Output byte/wd to DX port	0110111w			14
Repeated by count in CX (REP/REPE/REPZ/REPNE/REPNZ)				
MOVS = Move string	11110010	1010010w		8+8n
CMPS = Compare string	1111001z	1010011w		5+22n
SCAS = Scan string	1111001z	1010111w		5+15n
LODS = Load string	11110010	1010110w		6+11n
STOS = Store string	11110010	1010101w		6+9n
INS = Input string	11110010	0110110w		8+8n
OUTS = Output string	11110010	0110111w		8+8n
CONTROL TRANSFER				
CALL = **Call:**				
Direct within segment	11101000	disp-low	disp-high	15
Register/memory indirect within segment	11111111	mod 0 1 0 r/m		13/19
Direct intersegment	10011010	segment offset		23
		segment selector		
Indirect intersegment	11111111	mod 0 1 1 r/m	(mod ≠ 11)	38
JMP = **Unconditional jump:**				
Short/long	11101011	disp-low		14
Direct within segment	11101001	disp-low	disp-high	14
Register/memory indirect within segment	11111111	mod 1 0 0 r/m		11/17
Direct intersegment	11101010	segment offset		14
		segment selector		
Indirect intersegment	11111111	mod 1 0 1 r/m	(mod ≠ 11)	26

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
RET = **Return from CALL:**						
Within segment	11000011				16	
Within seg adding immed to SP	11000010	data-low	data-high		18	
Intersegment	11001011				22	
Intersegment adding immediate to SP	11001010	data-low	data-high		25	
JE/JZ = Jump on equal/zero	01110100	disp			4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100	disp			4/13	
JLE/JNG = Jump on less or equal/not greater	01111110	disp			4/13	
JB/JNAE = Jump on below/not above or equal	01110010	disp			4/13	
JBE/JNA = Jump on below or equal/not above	01110110	disp			4/13	
JP/JPE = Jump on parity/parity even	01111010	disp			4/13	
JO = Jump on overflow	01110000	disp			4/13	
JS = Jump on sign	01111000	disp			4/13	
JNE/JNZ = Jump on not equal/not zero	01110101	disp			4/13	
JNL/JGE = Jump on not less/greater or equal	01111101	disp			4/13	
JNLE/JG = Jump on not less or equal/greater	01111111	disp			4/13	
JNB/JAE = Jump on not below/above or equal	01110011	disp			4/13	
JNBE/JA = Jump on not below or equal/above	01110111	disp			4/13	
JNP/JPO = Jump on not par/par odd	01111011	disp			4/13	
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					15	
L = 1					25	
L > 1					22+16(n−1)	
LEAVE = Leave Procedure	11001001				8	
INT = **Interrupt:**						
Type specified	11001101	type			47	
Type 3	11001100				45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	11001110				48/4	
IRET = Interrupt return	11001111				28	
BOUND = Detect value out of range	01100010	mod reg r/m			33–35	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
PROCESSOR CONTROL			
CLC = Clear carry	11111000	2	
CMC = Complement carry	11110101	2	
STC = Set carry	11111001	2	
CLD = Clear direction	11111100	2	
STD = Set direction	11111101	2	
CLI = Clear interrupt	11111010	2	
STI = Set interrupt	11111011	2	
HLT = Halt	11110100	2	
WAIT = Wait	10011011	6	if $\overline{TEST}$ = 0
LOCK = Bus lock prefix	11110000	2	
NOP = No Operation	10010000	3	
	(TTT LLL are opcode to processor extension)		

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

The sections significantly revised since version -003 are:

Front Page	Deleted references to burn-in devices.
Local Bus Controller and Reset	Clarified effects of excessive loading on pins with internal pullup devices. Equivalent resistance no longer shown.
D.C. Characteristics	Renamed V_{CLI} to V_{IL1}. Renamed V_{CHI} to V_{IH3}. Changed V_{OH} (min.) from 0.8 V_{CC} to V_{CC} – 0.5V. Changed I_{CC} (max.) from 180 mA to 150 mA at 16 MHz, 150 mA to 120 mA at 12.5 mA, and 100 mA to 120 mA at 10 MHz. Changed V_{CLO} (max.) from 0.5V to 0.45V. Changed V_{CHO} (min.) from 0.8 V_{CC} to V_{CC} – 0.5V. Clarified effect of excessive loading on pins with internal pullup devices.
Power Supply Current	Added equation and graph for maximum current.
A.C. Characteristics	Many timings changed (all listed in ns): T_{DVCL} (min.) at 16 MHz from 10 to 15; T_{CLDX} (min.) from 5 to 3; T_{CLAV} (max.) at 10 MHz from 50 to 44; T_{CHCV} (max.) from 45 to 44 at 10 MHz, and from 37 to 36 at 12.5 MHz; T_{LHLL} (min.) from T_{CLCL} – 30 to T_{CLCL} – 15; T_{LLAX} (min.) at 10 MHz from T_{CHCL} – 20 to T_{CHCL} – 15; T_{CVCTV} (max.) from 56 to 44 at 10 MHz and from 47 to 37 at 12.5 MHz; T_{CVDEX} (max.) from 56 to 44 at 10 MHz, 47 to 37 at 12.5 MHz, and from 35 to 31 at 16 MHz; T_{RHAV} (min.) from T_{CLCL} – 40 at 10 MHz and T_{CLCL} – 20 at 12.5 MHz and 16 MHz to T_{CLCL} – 15 at all frequencies; T_{RLRH} (min.) from 2 T_{CLCL} – 46 to 2 T_{CLCL} – 30 at 10 MHz, from 2 T_{CLCL} – 40 to 2 T_{CLCL} – 25 at 12.5 MHz, and 2 T_{CLCL} – 30 to 2 T_{CLCL} – 25 at 16 MHz; T_{WLWH} (min.) from 2 T_{CLCL} – 34 to 2 T_{CLCL} – 30 at 10 MHz, and 2 T_{CLCL} – 30 to 2 T_{CLCL} – 25 at 12.5 MHz; T_{AVLL} (min.) from T_{CLCH} – 19 to T_{CLCH} – 18 at 10 MHz; T_{CLSH} (max.) at 10 MHz from 50 to 46; T_{CLTMV} (max.) from 48 to 40 at 10 MHz, 40 to 33 at 12.5 MHz, and 30 to 27 at 16 MHz; T_{CLRO} (max.) from 48 to 40 at 10 MHz, 40 to 33 at 12.5 MHz, and 30 to 27 at 16 MHz; T_{CHQSV} (max.) from 28 to 37 at 10 MHz, 28 to 32 at 12.5 MHz, and 25 to 30 at 16 MHz; T_{CHDX} (min.) from 5 to 10; T_{CLLV} (max.) at 10 MHz from 45 to 40 and at 12.5 MHz from 40 to 37; T_{CLCSV} (max.) from 45 to 42 at 10 MHz; T_{CHCSX} (max.) from 32 to 35 at 10 MHz, 28 to 30 at 12.5 MHz, and 23 to 25 at 16 MHz; and T_{CH1CH2} and T_{CL2CL1} (max.) at 16 MHz from 8 to 10. Added new timings for T_{WHDEX}, T_{RHLH}, and T_{WHLH}. Established min. timing for T_{CLCSV}.
Timing Waveforms	Section rearranged to show waveforms on same or facing page relative to corresponding tabular data. T_{CLSRY} drawn to same clock edge as T_{SRYCL}. Drawing changed to indicate one less clock between HOLD inactive and HLDA inactive.
Specification Level Markings	New Section.

The sections significantly revised since version -002 are:

Block Diagram	Redrawn to illustrate numerics coprocessor interface.
Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity. Interrupt Type 16 listed.
ESC Opcode Exception Description	Note added concerning ESC trap.
Oscillator Configurations	Deleted drive of X2 with inverted X1.
RESET Logic	Deleted paragraph concerning setup times for synchronization of multiple processors.
Local Bus Arbitration	Added description of HLDA when a refresh cycle is pending.
Local Bus Controller and Reset	Added description of pullup devices for appropriate pins.
DMA Controller	Added reminder to initialize transfer count registers and pointer registers.
Timers	Added reminder to intialize count registers.
DRAM Refresh Addresses	Refresh address counter described in figure.
D.C. Characteristics	V_{IH2} indicated for SRDY, ARDY. I_{CC} (max.) now indicated for all devices.
Power Supply Current	Typical I_{CC} indicated.
A.C. Characteristics	Input V_{IH} test condition at X1 added. T_{CLDOX}, T_{CVCTV}, T_{CVCTX}, T_{CLHAV}, and T_{CLLV} minimums reduced from 5 ns to 3 ns. T_{CLCH} (min.) and T_{CHCL} (min.) relaxed by 2 ns. Added reminder that T_{SRYCL} and T_{CLSRY} must be met.
Explanation of the A.C. Symbols	New Section.
Major Cycle Timing Waveforms	T_{DXDL} indicated in Read Cycle. T_{CLRO} indicated.
Rise/Fall and Capacitive Derating Curves	New Figures added.
Instruction Set Summary	ESC instruction clock count deleted.

The sections significantly revised since version -001 are:

Pin Description Table	Noted $\overline{RES}$ to be low more than 4 clocks.
Oscillator Configurations	Added reminder not to drive X2.
DMA Transfer Rate Table	Corrected to reflect 16 MHz capability.
DMA Control Bit Descriptions	Moved and clarified note concerning TC condition for ST/$\overline{STOP}$ clearing during unsynchronized transfers.
Interrupt Controller, etc.	Renamed iRMX Mode to Slave Mode.
Interrupt Request Register	Noted that D0 and D1 are read/write, others read-only.
DRAM Refresh Addresses	Added figure to explain refresh address bits.
A.C. Characteristics	Many timings changed (all listed in ns): T_{CLDX} (min.) from 8 to 5; T_{SRYCL} (min.) from 20 to 15; T_{HVCL} (min.) from 20 to 15; T_{INVCH} (min.) from 25 to 15; T_{INVCL} (min.) from 20 to 15; T_{CLAV} at 12.5 MHz from 4–33 to 5–36; T_{CLAV} at 16 MHz from 4–30 to 5–33; T_{CLAX} (min.) to 0; T_{CLDV} (min.) at 10 MHz from 10 to 5; T_{CLDV} (min.) at 12.5 MHz from 10–33 to 5–36; T_{CLDV} (min.) at 16 MHz from 10–30 to 5–33; T_{CLDOX} (min.) from 10 at 10 MHz and 8 at 12.5 MHz to 5 at both frequencies; T_{CVCTV} (max.) and T_{CHCTV} (max.) at 16 MHz from 25 to 31; T_{CHCTV} (min.) and T_{CVDEX} (min.) both from 10 at 10 MHz and 8 at 12.5 MHz to 5 at both frequencies; T_{CVCTX} (max.) at 16 MHz from 25 to 33; T_{CLRL} at 10 MHz from 10–56 to 5–44; T_{CLRL} at 12.5 MHz from 8–47 to 5–35; T_{CLRL} (max.) at 16 MHz from 25 to 31; T_{CLRH} (min.) at 10 MHz from 10 to 5 and at 12.5 MHz from 8 to 5; T_{CHSV} (min.) at 10 MHz from 10 to 5 and at 12.5 MHz from 8 to 5; T_{CHSV} (max.) at 16 MHz from 25 to 31; T_{CLSH} (min.) at 10 MHz from 10 to 5 and at 12.5 MHz from 8 to 5; T_{CHQSV} (max.) at 12.5 MHz from 23 to 28 and at 16 MHz from 23 to 25; T_{CHDX} (min.) at 10 MHz from 10 to 5 and at 12.5 MHz from 8 to 5; T_{AVCH} (min.) to 0; T_{CLLV} (max.) at 10 MHz from 60 to 45 and at 12.5 MHz from 55 to 40 and at 16 MHz from 40 to 35; T_{DXDL} (min.) to 0; T_{CXCSX} (min.) from 35 at 10 MHz and 29 at 12.5 MHz and 25 at 16 MHz to $T_{CLCH} - 10$ at all frequencies; T_{CHCSX} (min.) at 12.5 MHz and 16 MHz from 4–23 to 5–28 and 5–23 respectively.
Execution Timings	Clarified effect of bus width.

SPECIFICATION LEVEL MARKINGS

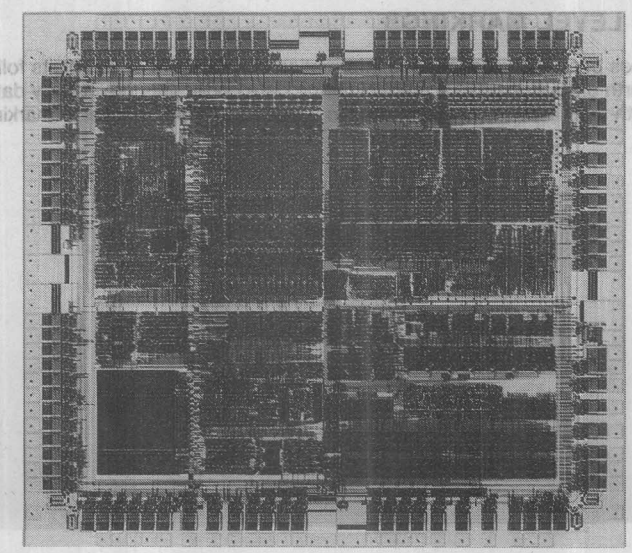
Current 80C186 devices bear backside lot code information consisting of seven digits followed by letters. The second, third, and fourth digits comprise a manufacturing date code. This preliminary data sheet applies only to 80C186 devices with a date code corresponding to week 25 of 1989 (backside markings x925xxx XXX) or later.

80C186EB-16, -13, -8
16-BIT HIGH-INTEGRATION EMBEDDED PROCESSOR

- **Full Static Operation**
- **True CMOS Inputs and Outputs**
- **−40°C to +85°C Operating Temperature Range**

- **Integrated Feature Set**
  - **Low-Power Static CPU Core**
  - **Two Independent UARTs each with an Integral Baud Rate Generator**
  - **Two 8-Bit Multiplexed I/O Ports**
  - **Programmable Interrupt Controller**
  - **Three Programmable 16-Bit Timer/Counters**
  - **Clock Generator**
  - **Ten Programmable Chip Selects with Integral Wait-State Generator**
  - **Memory Refresh Control Unit**
  - **System Level Testing Support (ONCE™ Mode)**
- **Direct Addressing Capability to 1 Mbyte Memory and 64 Kbyte I/O**
- **Speed Versions Available:**
  - **16 MHz (80C186EB-16)**
  - **13 MHz (80C186EB-13)**
  - **8 MHz (80C186EB-8)**
- **Low-Power Operating Modes:**
  - **Idle Mode Freezes CPU Clocks but keeps Peripherals Active**
  - **Powerdown Mode Freezes All Internal Clocks**
- **Complete System Development Support**
  - **ASM86 Assembler, PL/M 86, Pascal 86, Fortran 86, C-86, and System Utilities**
  - **In-Circuit Emulator (ICE™-186EB)**
- **Supports 80C187 Numeric Coprocessor Interface (N80C186EB Only)**
- **Available In:**
  - **80-Pin Quad Flat Pack (S80C186EB)**
  - **84-Pin Plastic Leaded Chip Carrier (N80C186EB)**

The 80C186EB is a second generation CHMOS High-Integration microprocessor. It has features that are new to the 80C186 family and include a STATIC CPU core, an enhanced Chip Select decode unit, two independent Serial Channels, I/O ports, and the capability of Idle or Powerdown low power modes.



270803-37

July 1990
Order Number: 270803-002

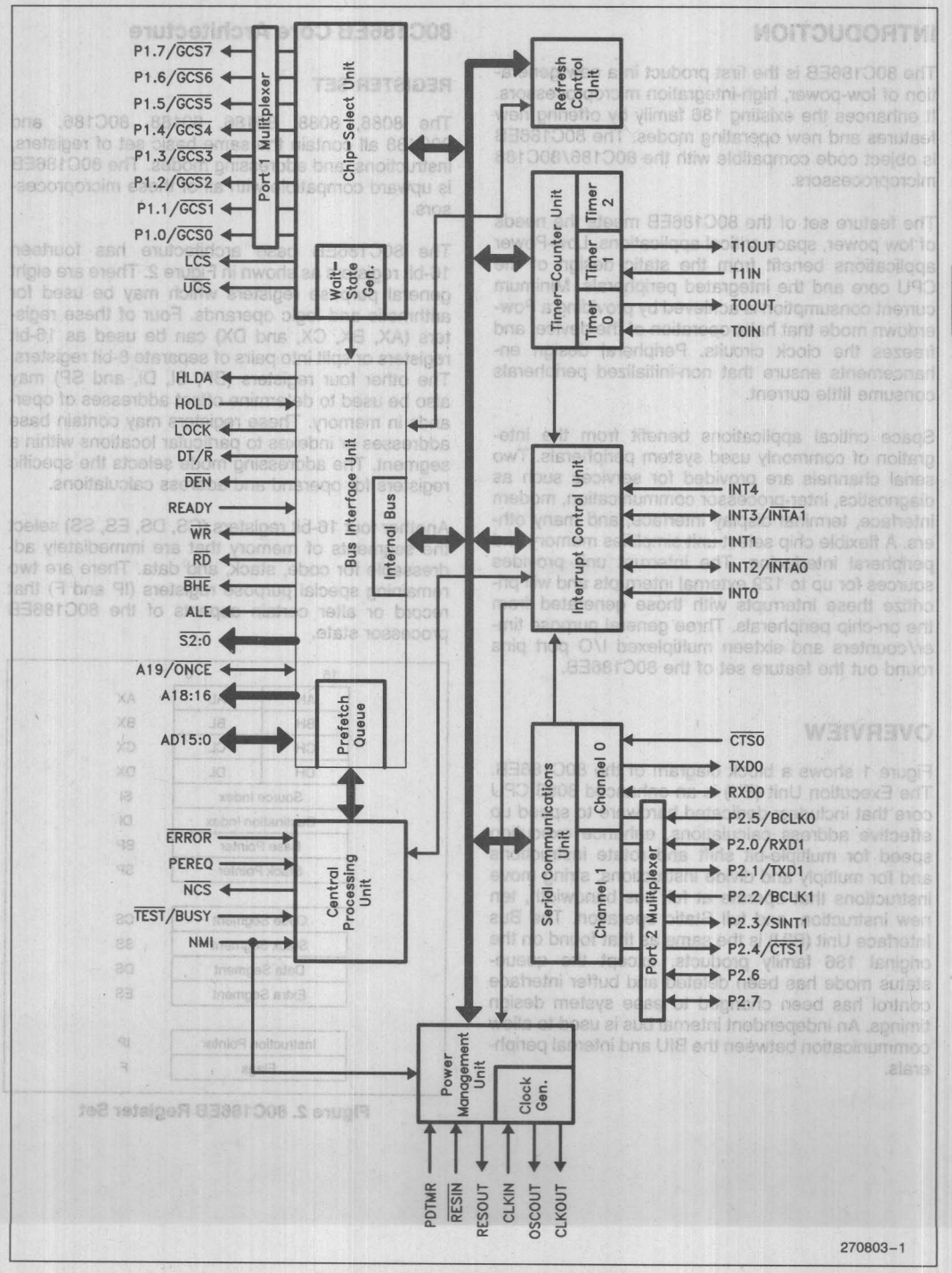


Figure 1. 80C186EB Block Diagram

consume little current.

Space critical applications benefit from the integration of commonly used system peripherals. Two serial channels are provided for services such as diagnostics, inter-processor communication, modem interface, terminal display interface, and many others. A flexible chip select unit simplifies memory and peripheral interfacing. The interrupt unit provides sources for up to 129 external interrupts and will prioritize these interrupts with those generated from the on-chip peripherals. Three general purpose timer/counters and sixteen multiplexed I/O port pins round out the feature set of the 80C186EB.

OVERVIEW

Figure 1 shows a block diagram of the 80C186EB. The Execution Unit (EU) is an enhanced 8086 CPU core that includes: dedicated hardware to speed up effective address calculations, enhance execution speed for multiple-bit shift and rotate instructions and for multiply and divide instructions, string move instructions that operate at full bus bandwidth, ten new instruction, and full Static operation. The Bus Interface Unit (BIU) is the same as that found on the original 186 family products, except the queue-status mode has been deleted and buffer interface control has been changed to ease system design timings. An independent internal bus is used to allow communication between the BIU and internal peripherals.

also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Another four 16-bit registers (CS, DS, ES, SS) select the segments of memory that are immediately addressable for code, stack, and data. There are two remaining special purpose registers (IP and F) that record or alter certain aspects of the 80C186EB processor state.

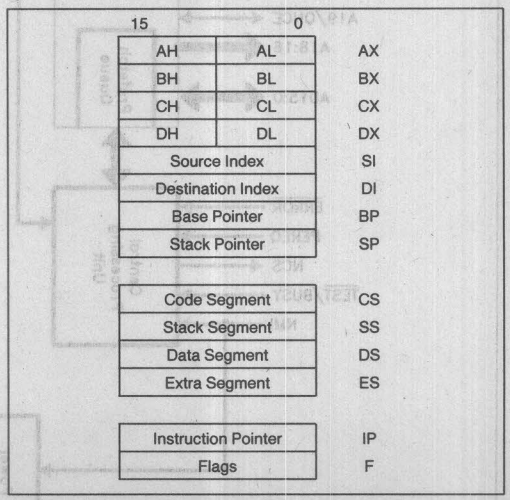


Figure 2. 80C186EB Register Set

INSTRUCTION SET

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80C186EB instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory.

MEMORY ORGANIZATION

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base segment values are contained in one of four internal segment registers (code, data stack, extra). The physical address is calculated by shifting the base value left by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 3). A 20-bit address allows for a 1 MByte address size.

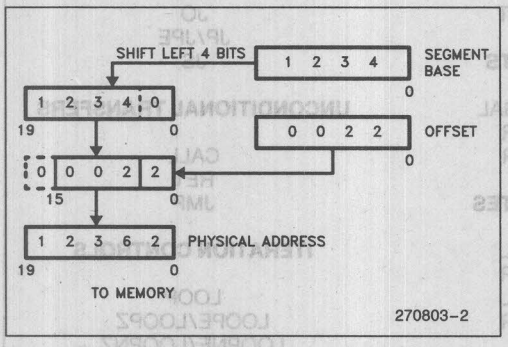


Figure 3. Two Component Address

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for a physical address generation is implied by the addressing mode used (see Table 1). Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

Table 1. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data
Stack	Stack (SS)	All stack pushes and pops; any memory references which use the BP register as a base
External	Extra (ES)	All String instruction references which use the DI register as an index
Local Data	Data (DS)	All other data references

ADDRESSING MODES

The 80C186EB provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

GENERAL PURPOSE

MOV
PUSH
POP
PUSHA
POPA
XCHG
XLAT

INPUT/OUTPUT

IN
OUT

ADDRESS OBJECT

LEA
LDS
LES

FLAG TRANSFER

LAHF
SAHF
PUSHF
POPF

ADDITION

ADD
INC
AAA
DAA

SUBSTRACTION

SUB
SBB
DEC
NEG
CMP
AAS
DAS

MULTIPLICATION

MUL
IMUL
AAM

DIVISION

DIV
IDIV
AAD
CBW
CWD

STRING OPERATIONS

MOVS
INS
OUTS
CMPS
SCAS
LODS
STOS
REP
REPE/REPZ
REPNE/REPNZ

LOGICALS

NOT
AND
OR
XOR
TEST

SHIFTS

SHL/SAL
SHR
SAR

ROTATES

ROL
ROR
RCL
RCR

FLAG OPERATIONS

STC
CLC
CMC
STD
CLD
STI
CLI

EXTERNAL SYNCHRONIZATION

HLT
WAIT
LOCK

NO OPERATION

NOP

HIGH LEVEL INSTRUCTIONS

ENTER
LEAVE
BOUND

CONDITIONAL TRANSFERS

JA/JNBE
JAE/JNB
JB/JNAE
JBE/JNA
JC
JE/JZ
JG/JNLE
JGE/JNL
JL/JNGE
JLE/JNG
JNC
JNE/JNZ
JNO
JNP/JP0
JNS
JO
JP/JPE
JS

UNCONDITIONAL TRANSFERS

CALL
RET
JMP

ITERATION CONTROLS

LOOP
LOOPE/LOOPZ
LOOPNE/LOOPNZ
JCXZ

INTERRUPTS

INT
INTO
IRET

Figure 4. 80C186EB Instruction Set

- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an index register.
- *Based Indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

DATA TYPES

The 80C186EB directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using the 80C187 Numerics Coprocessor.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component, or a 16-bit segment base component and a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 Kbyte to 64 Kbytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.

chine state (F) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, software (program) initiated, and instruction exception initiated. Hardware initiated interrupts occur in response to an external or internal input and are classified as nonmaskable or maskable.

Programs may cause an interrupt by executing the "INT" instruction. Instruction exceptions occur when an illegal opcode has been fetched into the queue and is read by the execution unit. Another type of exception can be generated when executing an "ESC" instruction.

For all cases except the "ESC" exception, the return address from an exception will point at the instruction immediately following the instruction causing the exception. The return address after an "ESC" exception will point back to the ESC instruction causing the exception, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31 are reserved by Intel. Table 2 shows the 80C186EB predefined type and default priority levels. For each interrupt, an 8-bit vector (Vector Type) identifies the appropriate table entry. Multiplying the 8-bit vector by 4 defines the vector address. INT instructions contain or imply the vector type and allow access to all 256 interrupts.

Timer 0 Interrupt	8	20H	2	
Reserved	9–11	24H–2CH		
INT0 Interrupt	12	30H	5	
INT1 Interrupt	13	34H	6	
INT2 Interrupt	14	38H	7	
INT3 Interrupt	15	3CH	8	
Numerics Exception	16	40H	1	ESC OP-Codes
INT4 Interrupt	17	44H	4	
Timer1 Interrupt	18	48H	2A	
Timer2 Interrupt	19	4CH	2B	
UART 0 Receive Interrupt	20	50H	3	
UART 0 Transmit Interrupt	21	54H	3A	
Reserved	22–31	58H–7CH		

BUS INTERFACE UNIT

The 80C186EB core incorporates a bus controller that generates local bus control signals. In addition, it employs a HOLD/HLDA protocol to share the local bus with other bus masters.

The bus controller is responsible for generating 20 bits of address, read and write strobes, bus cycle status information, and data (for write operations) information. It is also responsible for reading data off the local bus during a read operation. A ready input pin is provided to extend a bus cycle beyond the minimum four states (clocks).

A HOLD/HLDA protocol is provided by the local bus controller to allow multiple bus masters to share the same local bus. When the 80C186EB relinquishes control of the local bus, it floats certain bus control signals to allow another bus master to drive these pins directly. Refer to the Pin Description section to determine which pins the 80C186EB will float during a HOLD/HLDA bus exchange.

The 80C186EB local bus controller also generates two control signals ($\overline{DEN}$ and DT/$\overline{R}$) when interfacing to external transceiver chips. (Both $\overline{DEN}$ and DT/$\overline{R}$ are available on the N80C186EB device, only $\overline{DEN}$ is available on the S80C186EB device.) This capability allows the addition of transceivers for simple buffering of the mulitplexed address/data bus.

CLOCK GENERATOR

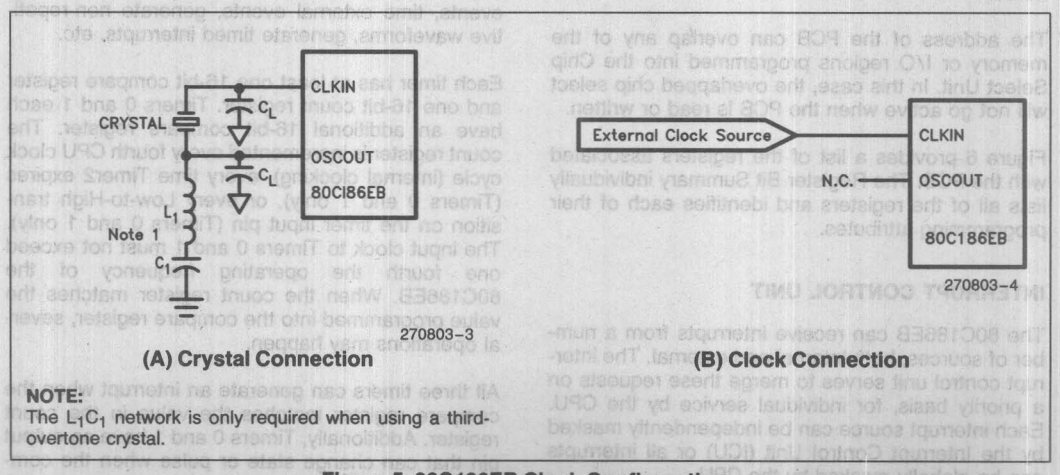
The 80C186EB provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, and two low-power operating modes.

The oscillator circuit is designed to be used with either a **parallel resonant** fundamental or third-overtone mode crystal network. Alternatively, the oscillator circuit may be driven from an external clock source. Figure 5 shows the various operating modes of the 80C186EB oscillator circuit.

The crystal or clock frequency chosen must be twice the required processor operating frequency due to the internal divide-by-two counter. This counter is used to drive all internal phase clocks and the external CLKOUT signal. CLKOUT is a 50% duty cycle processor clock and can be used to drive other system components. All A.C. timings are referenced to CLKOUT.

The following parameters are recommended when choosing a crystal:

Temperature Range:	Application Specific
ESR (Equivalent Series Resistance):	40Ω max
C0 (Shunt Capacitance of Crystal):	7.0 pF max
C1 (Load Capacitance):	20 pF ± 2 pF
Drive Level:	1 mW max



NOTE:
The L_1C_1 network is only required when using a third-overtone crystal.

Figure 5. 80C186EB Clock Configurations

80C186EB Peripheral Architecture

The 80C186EB has integrated several common system peripherals with a CPU core to create a compact, yet powerful system. The integrated peripherals are designed to be flexible and provide logical interconnections between supporting units (e.g., the interrupt control unit supports interrupt requests from the timer/counters or serial channels).

The list of integrated peripherals include:

- 7-Input Interrupt Control Unit
- 3-Channel Timer/Counter Unit
- 2-Channel Serial Communications Unit
- 10-Output Chip-Select Unit
- I/O Port Unit
- Refresh Control Unit
- Power Management Unit

The registers associated with each integrated peripheral are contained within a 128 x 16 register file called the Peripheral Control Block (PCB). The PCB can be located in either memory or I/O space on any 256 Byte address boundary. During bus cycles that access the PCB, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle). However, READY is ignored and the contents of the data bus during a read operation is ignored.

The address of the PCB can overlap any of the memory or I/O regions programmed into the Chip Select Unit. In this case, the overlapped chip select will not go active when the PCB is read or written.

Figure 6 provides a list of the registers associated with the PCB. The Register Bit Summary individually lists all of the registers and identifies each of their programming attributes.

INTERRUPT CONTROL UNIT

The 80C186EB can receive interrupts from a number of sources, both internal and external. The interrupt control unit serves to merge these requests on a priority basis, for individual service by the CPU. Each interrupt source can be independently masked by the Interrupt Control Unit (ICU) or all interrupts can be globally masked by the CPU.

Internal interrupt sources include the Timers and Serial channel 0. External interrupt sources come from the five input pins INT4:0. The NMI interrupt pin is not controlled by the ICU and is passed directly to the CPU. Although the Timer and Serial channel each have only one request input to the ICU, separate vector types are generated to service individual interrupts within the Timer and Serial channel units.

The 80C186EB ICU provides a mechanism for expanding the number of external interrupt sources. Two pairs of pins can be independently configured to support an external slave interrupt controller (82C59A). Each pair of external pins can be expanded to support 64 interrupts, making it possible for the 80C186EB to support a total of 129 external interrupts.

The ICU may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the ICU whenever it is convenient.

TIMER/COUNTER UNIT

The 80C186EB Timer/Counter Unit (TCU) provides three 16-bit programmable timers. Two of these are highly flexible and are connected to external pins for control or clocking. A third timer is not connected to any external pins and can only be clocked internally. However, it can be used to clock the other two timer channels. The TCU can be used to count external events, time external events, generate non-repetitive waveforms, generate timed interrupts. etc.

Each timer has at least one 16-bit compare register and one 16-bit count register. Timers 0 and 1 each have an additional 16-bit compare register. The count register is incremented every fourth CPU clock cycle (internal clocking), every time Timer2 expires (Timers 0 and 1 only), or every Low-to-High transition on the timer input pin (Timers 0 and 1 only). The input clock to Timers 0 and 1 must not exceed one fourth the operating frequency of the 80C186EB. When the count register matches the value programmed into the compare register, several operations may happen.

All three timers can generate an interrupt when the compare register matches the value in the count register. Additionally, Timers 0 and 1 have an output pin that can change state or pulse when the compare condition occurs.

PCB Offset	Function
00H	Reserved
02H	End Of Interrupt
04H	Poll
06H	Poll Status
08H	Interrupt Mask
0AH	Priority Mask
0CH	In-Service
0EH	Interrupt Request
10H	Interrupt Status
12H	Timer Control
14H	Serial Control
16H	INT4 Control
18H	INT0 Control
1AH	INT1 Control
1CH	INT2 Control
1EH	INT3 Control
20H	Reserved
22H	Reserved
24H	Reserved
26H	Reserved
28H	Reserved
2AH	Reserved
2CH	Reserved
2EH	Reserved
30H	Timer0 Count
32H	Timer0 Compare A
34H	Timer0 Compare B
36H	Timer0 Control
38H	Timer1 Count
3AH	Timer1 Compare A
3CH	Timer1 Compare B
3EH	Timer1 Control

PCB Offset	Function
40H	Timer2 Count
42H	Timer2 Compare
44H	Reserved
46H	Timer2 Control
48H	Reserved
4AH	Reserved
4CH	Reserved
4EH	Reserved
50H	Reserved
52H	Port0 Pin
54H	Port0 Control
56H	Port0 Latch
58H	Port1 Direction
5AH	Port1 Pin
5CH	Port1 Control
5EH	Port1 Latch
60H	Serial0 Baud
62H	Serial0 Count
64H	Serial0 Control
66H	Serial0 Status
68H	Serial0 RBUF
6AH	Serial0 TBUF
6CH	Reserved
6EH	Reserved
70H	Serial1 Baud
72H	Serial1 Count
74H	Serial1 Control
76H	Serial1 Status
78H	Serial1 RBUF
7AH	Serial1 TBUF
7CH	Reserved
7EH	Reserved

PCB Offset	Function
80H	GCS0 Start
82H	GCS0 Stop
84H	GCS1 Start
86H	GCS1 Stop
88H	GCS2 Start
8AH	GCS2 Stop
8CH	GCS3 Start
8EH	GCS3 Stop
90H	GCS4 Start
92H	GCS4 Stop
94H	GCS5 Start
96H	GCS5 Stop
98H	GCS6 Start
9AH	GCS6 Stop
9CH	GCS7 Start
9EH	GCS7 Stop
A0H	LCS Start
A2H	LCS Stop
A4H	UCS Start
A6H	UCS Stop
A8H	Relocation
AAH	Reserved
ACH	Reserved
AEH	Reserved
B0H	Refresh Base
B2H	Refresh Time
B4H	Refresh Control
B6H	Refresh Address
B8H	Power Control
BAH	Reserved
BCH	Step ID
BEH	Reserved

PCB Offset	Function
C0H	Reserved
C2H	Reserved
C4H	Reserved
C6H	Reserved
C8H	Reserved
CAH	Reserved
CCH	Reserved
CEH	Reserved
D0H	Reserved
D2H	Reserved
D4H	Reserved
D6H	Reserved
D8H	Reserved
DAH	Reserved
DCH	Reserved
DEH	Reserved
E0H	Reserved
E2H	Reserved
E4H	Reserved
E6H	Reserved
E8H	Reserved
EAH	Reserved
ECH	Reserved
EEH	Reserved
F0H	Reserved
F2H	Reserved
F4H	Reserved
F6H	Reserved
F8H	Reserved
FAH	Reserved
FCH	Reserved
FEH	Reserved

Figure 6. 80C186EB Peripheral Control Block Registers

Other timer programming options include:

- All three timers can be set to halt or continue after a compare match.
- Timers 0 and 1 can be reset or retriggered using their respective input pins.
- TCU registers can be read or written at any time.

SERIAL COMMUNICATIONS UNIT

The Serial Control Unit (SCU) of the 80C186EB contains two independent channels. Each channel is identical in operation except that only channel 0 is supported by the integrated interrupt controller (channel 1 has an external interrupt pin). Each channel has its own baud rate generator that is independent of the Timer/Counter Unit, and can be internally or externally clocked up to one half the 80C186EB operating frequency.

Each serial channel supports one synchronous and four asynchronous modes of operation and is compatible with the serial ports of the MCS®-51 and MCS®-96 family of products. Data field length can be 7-, 8-, or 9-bits with optional odd or even parity (generated and checked) and one stop bit (generated and checked). The 9-bit mode has an optional "addressing" feature to simplify interprocessor communication. Each serial port is doubled buffered in both transmit and receive operation (data can be read or written to a buffer register while data is shifted into or out of a shifting register, respectively).

A Clear-To-Send input pin can be programmed to prevent data transmission if the pin is sampled inactive. Serial channel 0 is supported by the integrated interrupt controller, providing separate receive and transmit vector types. Serial channel 1 has an external interrupt pin which OR's the receive and transmit interrupts. This external interrupt pin can be routed to either the external pins of the ICU, the NMI pin, or any other external system interrupt controller. Status bits are provided to allow polling of the serial channels if interrupts are not desired.

Independent baud rate generators are provided for each of the serial channels. For the asynchronous modes, the generator supplies an 8x baud clock to both the receive and transmit register logic. A 1x baud clock is provided in the synchronous mode.

Additional features of the SCU include:

- Framing error, receive buffer overrun error, and parity error detection.
- Break detect.
- Break send.

CHIP-SELECT UNIT

The 80C186EB Chip-Select Unit (CSU) integrates logic which provides up to ten programmable chip-selects to access both memories and peripherals. In addition, each chip-select can be programmed to automatically insert additional clocks (wait-states) into the current bus cycle and automatically terminate a bus cycle independent of the condition of the ready input pin.

Each of the chip-selects can be programmed to go active for either memory or I/O accesses. UCS is the only chip-select that is active after a reset and is enabled for memory addresses in the range 0FFC00H to 0FFFFFH (this allows a boot-ROM to be accessed using UCS). Every chip-select has a programmable start and stop register that defines the active region for the chip-select, and the ready characteristics for the region.

The start and stop address fields are 10 bits in length and are matched against the upper 10 bits of either the memory or I/O address. A 10-bit compare results in a granularity of 1 Kbytes for memory accesses and 64 bytes for I/O accesses. Each chip select can be disabled by programming its start address greater than its stop address or by clearing its enable bit.

Each chip-select can be programmed to automatically insert wait-states, and to control whether the external ready input is to be ignored or used. The 80C186EB bus controller will wait the programmed number of wait-states before the external ready pin can be used to extend or terminate the bus cycle.

Overlapping of chip-selects is allowed. However, each one that overlaps will go active. If any overlapping chip-select has been programmed to use external ready, the bus control unit will insert the least amount of programmed wait-states programmed before the external ready pin is used. If all overlapped chip-selects ignore external ready, the bus controller will insert the maximum number of programmed wait-states. Any chip-select that overlaps the Peripheral Control Block (PCB) will not go active for that portion of the address range allocated to the PCB.

The Generic Chip-Selects (GCS7:0) are multiplexed with an output only Port function. Any channel that is being used as a chip-select must be disabled as a port pin by correctly programming the port pin control registers (see the following section).

I/O PORT UNIT

The I/O Port Unit (IPU) on the 80C186EB supports two 8-bit channels of input, output, or input/output operation. Port 1 is multiplexed with the chip select pins and is output only. Most of Port 2 is multiplexed with the serial channel pins. Port 2 pins are limited to either an output or input function depending on the operation of the serial pin it is multiplexed with.

Two bits of Port 2 are not multiplexed with any other peripheral functions and can be used as either an input or an output function. A port direction register is used to define the function of the port pin. The output for these two pins are open drain.

Besides a direction register, each port channel has a data latch register, port pin register, and a port multiplexer control register.

REFRESH CONTROL UNIT

The Refresh Control Unit (RCU) automatically generates a periodic memory read bus cycle to keep dynamic or pseudo-static memory refreshed. A 9-bit counter controls the number of clocks between refresh requests.

A 12-bit address generator is maintained by the RCU and is presented on the A12:1 address lines during the refresh bus cycle. The address generator is incremented only after the refresh bus cycle is run. This ensures that all address combinations will be presented to the memory array even if the refresh bus cycle is not run before another request is generated. Address bits A19:13 are programmable to allow the refresh address block to be located on any 8 Kbyte boundary.

The chip-select unit is active during refresh bus cycles. This means that a chip-select will go active if the refresh address is within the limits specified for the channel. In addition, $\overline{BHE}$ and A0 are both driven high during refresh bus cycles (this is normally an invalid bus condition). Data on the AD15:0 bus is ignored.

A pending refresh request will attempt to abort a HOLD/HLDA bus exchange. HLDA is deasserted when a refresh request is pending and a bus HOLD is already in progress. HOLD must then be released in order for the 80C186EB to execute the refresh bus cycle.

POWER MANAGEMENT UNIT

The 80C186EB Power Management Unit (PMU) is provided to control the power consumption of the device. The PMU provides three power modes: Active, Idle, and Powerdown.

Active Mode indicates that all units on the 80C186EB are functional and the device consumes maximum power (depending on the level of peripheral operation). Idle Mode freezes the clocks of the Execution and Bus units at a logic zero state (all peripherals continue to operate normally). An unmasked interrupt, NMI, or reset will cause the 80C186EB to exit the Idle mode.

The Powerdown mode freezes all internal clocks at a logic zero level and disables the crystal oscillator. All internal registers hold their values provided V_{CC} is maintained. Current consumption is reduced to just transistor junction leakage. An NMI or processor reset will cause the 80C186EB to exit the Powerdown Mode. A timing pin is provided to establish the length of time between exiting Powerdown and resuming device operation. (Length of time depends on startup time of crystal oscillator and is application dependent.)

80C187 Interface

The 80C186EB (PLCC package only) supports the direct connection of the 80C187 Numerics Coprocessor.

ONCE™ Test Mode

To facilitate testing and inspection of devices when fixed into a target system, the 80C186EB has a test mode available which forces all output and input/output pins to be placed in the high-impedance state. ONCE stands for "ON Circuit Emulation". The ONCE mode is selected by forcing the A19/$\overline{ONCE}$ pin LOW (0) during a processor reset (this pin is weakly held to a HIGH (1) level) while $\overline{RESIN}$ is active.

PACKAGE INFORMATION

This section describes the pins, pinouts, and thermal characteristics for the 80C186EB in the Plastic Leaded Chip Carrier (PLCC) package and Quad Flat Pack (QFP) package. For complete package specifications and information, see the Intel Packaging Outlines and Dimensions Guide (Order Number: 231369).

Pin Descriptions

The 80C186EB pins are described in this section. Table 3 presents the legend for interpreting the pin descriptions in Table 4. Figure 7 provides an example pin description entry. The "I/O" signifies that the pins are bidirectional (i.e., have both an input and output function). The "S" indicates that, as an input, the signal is synchronized to CLKOUT for proper operation. The "H(Z)" indicates that these pins will float while the processor is in the Hold Acknowledge state. R(Z) indicates that these pins will float while $\overline{RESIN}$ is low. P(X) Indicates that these pins will retain its current value when Idle or Powerdown Modes are entered.

All pins float while the processor is in the ONCE™ Mode.

Name	Type	Description
AD15:0	I/O S(L) H(Z) R(Z) P(X)	These pins provide a multiplexed ADDRESS and DATA bus. During the address phase of the bus cycle, address bits 0 through 15 are presented on the bus and can be latched using ALE. 8- or 16-bit data information are transferred during the data phase of the bus cycle.

Figure 7. Example Pin Description Entry

Table 3. Pin Description Nomenclature

Symbol	Description
I	Input Only Pin
O	Output Only Pin
I/O	Pin can be either input or output
—	Pin "must be" connected as described
S(..)	Synchronous. Input must meet setup and hold times for proper operation of the processor. The pin is: S(E) edge sensitive S(L) level sensitive
A(..)	Asynchronous. Input must meet setup and hold only to guarantee recognition. The pin is: A(E) edge sensitive A(L) level sensitive
H(..)	While the processor's bus is in the Hold Acknowledge state, the pin: H(1) is driven to V_{CC} H(0) is driven to V_{SS} H(Z) floats H(Q) remains active H(X) retains current state
R(..)	While the processor's $\overline{RES}$ line is low, the pin: R(1) is driven to V_{CC} R(0) is driven to V_{SS} R(Z) floats R(WH) weak pullup R(WL) weak pulldown
P(..)	While Idle or Powerdown modes are active, the pin: P(Z) is driven to V_{CC} P(0) is driven to V_{SS} P(Z) floats P(Q) remains active(1) P(X) retains current state

NOTE:
1. Any pin that specifies P(Q) are valid for Idle Mode. All pins are P(X) for Powerdown Mode.

Table 3. 80C186EB Pin Descriptions

Name	Type	Description
V_{CC}		**POWER** connections consist of four pins which must be shorted externally to a V_{CC} board plane.
V_{SS}		**GROUND** connections consist of six pins which must be shorted externally to a V_{SS} board plane.
CLKIN	I A(E)	**CLock INput** is an input for an external clock. An external oscillator operating at two times the required 80C186EB operating frequency can be connected to CLKIN. For crystal operation, CLKIN (along with OSCOUT) are the crystal connections to an internal Pierce oscillator.
OSCOUT	O H(Q) R(Q) P(X)	**OSCillator OUTput** is only used when using a crystal to generate the external clock. OSCOUT (along with CLKIN) are the crystal connections to an internal Pierce oscillator. This pin is not to be used as 2X clock output for non-crystal applications (i.e., this pin is N.C. for non-crystal applications).
CLKOUT	O H(Q) R(Q) P(1)	**CLock OUTput** provides a timing reference for inputs and outputs of the processor, and is one-half the input clock (CLKIN) frequency. CLKOUT has a 50% duty cycle and transistions every falling edge of CLKIN.
$\overline{RESIN}$	I A(L)	**RESet IN** causes the 80C186EB to immediately terminate any bus cycle in progress and assume an initialized state. All pins will be driven to a known state, and RESOUT will also be driven active. The rising edge (low-to-high) transition synchronizes CLKOUT with $\overline{CLKIN}$ before the 80C186EB begins fetching opcodes at memory location 0FFFF0H.
RESOUT	O H(0) R(1) P(0)	**RESet OUTput** that indicates the 80C186EB is currently in the reset state. RESOUT will remain active as long as $\overline{RESIN}$ remains active.
PDTMR	I/O A(L) H(WH) R(Z) P(WH)	**Power-Down TiMeR** pin (normally connected to an external capacitor) that determines the amount of time the 80C186EB waits after an exit from power down before resuming normal operation. The duration of time required will depend on the startup characteristics of the crystal oscillator.
NMI	I A(E)	**Non-Maskable Interrupt** input causes a TYPE-2 interrupt to be serviced by the CPU. NMI is latched internally.
$\overline{TEST}$/BUSY	I A(E)	**TEST** is used during the execution of the WAIT instruction to suspend CPU operation until the pin is sampled active (LOW). $\overline{TEST}$ is alternately known as BUSY when interfacing with an 80C187 numerics coprocessor.
AD15:0	I/O S(L) H(Z) R(Z) P(X)	These pins provide a multiplexed ADDRESS and DATA bus. During the address phase of the bus cycle, address bits 0 through 15 are presented on the bus and can be latched using ALE. 8- or 16-bit data information is transferred during the data phase of the bus cycle.
A18:16 A19/$\overline{ONCE}$	H(Z) R(WH) P(X)	These pins provide multiplexed ADDRESS during the address phase of the bus cycle. Address bits 16 through 19 are presented on these pins and can be latched using ALE. These pins are driven to a logic 0 during the data phase of the bus cycle. During a processor reset ($\overline{RESIN}$ active), A19/$\overline{ONCE}$ is used to enable ONCE mode. A18:16 must not be driven low during reset or improper 80C186EB operation may result.

Table 3. 80C186EB Pin Descriptions (Continued)

Name	Type	Description
$\overline{S2:0}$	O H(Z) R(1) P(1)	Bus cycle **Status** are encoded on these pins to provide bus transaction information. $\overline{S2:0}$ are encoded as follows: $\overline{S2}$ $\overline{S1}$ $\overline{S0}$ Bus Cycle Initiated 0 0 0 Interrupt Acknowledge 0 0 1 Read I/O 0 1 0 Write I/O 0 1 1 Processor HALT 1 0 0 Queue Instruction Fetch 1 0 1 Read Memory 1 1 0 Write Memory 1 1 1 Passive (no bus activity)
ALE	O H(0) R(0) P(0)	**Address Latch Enable** output is used to strobe address information into a transparent type latch during the address phase of the bus cycle.
$\overline{BHE}$	O H(Z) R(Z) P(X)	**Byte High Enable** output to indicate that the bus cycle in progress is transferring data over the upper half of the data bus. $\overline{BHE}$ and A0 have the following logical encoding: A0 $\overline{BHE}$ Encoding 0 0 Word Transfer 0 1 Even Byte Transfer 1 0 Odd Byte Transfer 1 1 Refresh Operation
$\overline{RD}$	O H(Z) R(Z) P(1)	**ReaD** output signals that the accessed memory or I/O device must drive data information onto the data bus.
$\overline{WR}$	O H(Z) R(Z) P(1)	**WRite** output signals that data available on the data bus are to be written into the accessed memory or I/O device.
READY	I A(L) S(L)	**READY** input to signal the completion of a bus cycle. READY must be active to terminate any 80C186EB bus cycle, unless it is ignored by correctly programming the Chip-Select Unit.
$\overline{DEN}$	O H(Z) R(Z) P(1)	**Data ENable** output to control the enable of bi-directional transceivers when buffering a 80C186EB system. $\overline{DEN}$ is active only when data is to be transferred on the bus.
DT/$\overline{R}$	O H(Z) R(Z) P(X)	**Data Transmit/Receive** output controls the direction of a bi-directional buffer when buffering an 80C186EB system. DT/$\overline{R}$ is only available for the PLCC package (N80C186EB).
$\overline{LOCK}$	I/O H(Z) R(WH) P(1)	**LOCK** output indicates that the bus cycle in progress is not to be interrupted. The 80C186EB will not service other bus requests (such as HOLD) while $\overline{LOCK}$ is active. This pin is configured as a weakly held high input while $\overline{RESIN}$ is active and must not be driven low.

	P(1)	
$\overline{\text{ERROR}}$	I A(L)	**ERROR** input that indicates the last numerics coprocessor operation resulted in an exception condition. An interrupt TYPE 16 is generated if $\overline{\text{ERROR}}$ is sampled active at the beginning of a numerics operation. $\overline{\text{ERROR}}$ is not provided on the S80C186EB.
PEREQ	I A(L)	**CoProcessor REQuest** signals that a data transfer between an External Numerics Coprocessor and Memory is pending. PEREQ is not provided on the S80C186EB.
$\overline{\text{UCS}}$	O H(1) R(1) P(1)	**Upper Chip Select** will go active whenever the address of a memory or I/O bus cycle is within the address limitations programmed by the user. After reset, $\overline{\text{UCS}}$ is configured to be active for memory accesses between 0FFC00H and 0FFFFFH.
$\overline{\text{LCS}}$	O H(1) R(1) P(1)	**Lower Chip Select** will go active whenever the address of a memory bus cycle is within the address limitations programmed by the user. $\overline{\text{LCS}}$ is inactive after a reset.
P1.0/$\overline{\text{GCS0}}$ P1.1/$\overline{\text{GCS1}}$ P1.2/$\overline{\text{GCS2}}$ P1.3/$\overline{\text{GCS3}}$ P1.4/$\overline{\text{GCS4}}$ P1.5/$\overline{\text{GCS5}}$ P1.6/$\overline{\text{GCS6}}$ P1.7/$\overline{\text{GCS7}}$	O H(X)/H(1) R(1) P(X)/P(1)	These pins provide a multiplexed function. If enabled, each pin can provide a **Generic Chip Select** output which will go active whenever the address of a memory or I/O bus cycle is within the address limitations programmed by the user. When not programmed as a Chip-Select, each pin may be used as a general purpose output **Port.** As an output port pin, the value of the pin can be read internally.
T0OUT T1OUT	O H(Q) R(1) P(Q)	**Timer OUTput** pins can be programmed to provide a single clock or continuous waveform generation, depending on the timer mode selected.
T0IN T1IN	I A(L) A(E)	**Timer INput** is used either as clock or control signals, depending on the timer mode selected.

Table 3. 80C186EB Pin Descriptions (Continued)

Name	Type	Description
INT0 INT1 INT4	I A(E,L)	Maskable **INTerrupt** input will cause a vector to a specific Type interrupt routine. To allow interrupt expansion, INT0 and/or INT1 can be used with $\overline{\text{INTA0}}$ and $\overline{\text{INTA1}}$ to interface with an external slave controller.
INT2/$\overline{\text{INTA0}}$ INT3/$\overline{\text{INTA1}}$	I/O A(E,L) /H(1) R(Z) /P(1)	These pins provide a multiplexed function. As inputs, they provide a maskable **INTerrupt** that will cause the CPU to vector to a specific Type interrupt routine. As outputs, each is programmatically controlled to provide an INTERRUPT ACKNOWLEDGE handshake signal to allow interrupt expansion.
P2.7 P2.6	I/O A(L) H(X) R(Z) P(X)	BI-DIRECTIONAL, open-drain **Port** pins.
$\overline{\text{CTS0}}$ P2.4/$\overline{\text{CTS1}}$	I A(L)	**Clear-To-Send** input is used to prevent the transmission of serial data on the TXD signal pin. $\overline{\text{CTS1}}$ is multiplexed with an input only port function.
TXD0 P2.1/TXD1	O H(X)/H(Q) R(1) P(X)/P(Q)	**Transmit Data** output provides serial data information. TXD1 is multiplexed with an output only **Port** function. During synchronous serial communications, TXD will function as a clock output.
RXD0 P2.0/RXD1	I/O A(L) R(Z) H(Q) P(X)	**Receive Data** input accepts serial data information. RXD1 is multiplexed with an input only **Port** function. During synchronous serial communications, RXD is bi-directional and will become an output for transmission or data (TXD becomes the clock).
P2.5/BCLK0 P2.2/BCLK1	I A(L)/A(E)	**Baud CLocK** input can be used as an alternate clock source for each of the integrated serial channels. BCLKx is multiplexed with an input only **Port** function, and cannot exceed a clock rate greater than one-half the operating frequency of the 80C186EB.
P2.3/SINT1	O H(X)/H(Q) R(0) P(X)/P(Q)	**Serial INTerrupt** output will go active to indicate serial channel 1 requires service. SINT1 is multiplexed with an output only **Port** function.

80C186EB PINOUT

Tables 4 and 5 list the 80C186EB pin names with package location for the 84-pin Plastic Leaded Chip Carrier (PLCC) component. Figure 7 depicts the complete 80C186EB pinout (PLCC package) as viewed from the top side of the component (i.e., contacts facing down).

Tables 6 and 7 list the 80C186EB pin names with package location for the 80-pin Quad Flat Pack (QFP) component. Figure 8 depicts the complete 80C186EB (QFP package) as viewed from the top side of the component (i.e., contacts facing down).

Table 4. PLCC Pin Names with Package Location

Address/Data Bus	
Name	**Location**
AD0	61
AD1	66
AD2	68
AD3	70
AD4	72
AD5	74
AD6	76
AD7	78
AD8	62
AD9	67
AD10	69
AD11	71
AD12	73
AD13	75
AD14	77
AD15	79
A16	80
A17	81
A18	82
A19/$\overline{\text{ONCE}}$	83

Bus Control	
Name	**Location**
ALE	6
$\overline{\text{BHE}}$	7
$\overline{\text{S0}}$	10
$\overline{\text{S1}}$	9
$\overline{\text{S2}}$	8
$\overline{\text{RD}}$	4
$\overline{\text{WR}}$	5
READY	18
$\overline{\text{DEN}}$	11
DT/$\overline{\text{R}}$	16
$\overline{\text{LOCK}}$	15
HOLD	13
HLDA	12
V_{SS}	2, 22, 43
V_{SS}	63, 65, 84

Processor Control	
Name	**Location**
$\overline{\text{RESIN}}$	37
RESOUT	38
CLKIN	41
OSCOUT	40
CLKOUT	44
$\overline{\text{TEST}}$/BUSY	14
$\overline{\text{NCS}}$	60
PEREQ	39
$\overline{\text{ERROR}}$	3
PDTMR	36
NMI	17
INT0	31
INT1	32
INT2/$\overline{\text{INTA0}}$	33
INT3/$\overline{\text{INTA1}}$	34
INT4	35
V_{CC}	1, 23,
V_{CC}	42, 64

I/O	
Name	**Location**
$\overline{\text{UCS}}$	30
$\overline{\text{LCS}}$	29
P1.0/$\overline{\text{GCS0}}$	28
P1.1/$\overline{\text{GCS1}}$	27
P1.2/$\overline{\text{GCS2}}$	26
P1.3/$\overline{\text{GCS3}}$	25
P1.4/$\overline{\text{GCS4}}$	24
P1.5/$\overline{\text{GCS5}}$	21
P1.6/$\overline{\text{GCS6}}$	20
P1.7/$\overline{\text{GCS7}}$	19
T0OUT	45
T0IN	46
T1OUT	47
T1IN	48
RXD0	53
TXD0	52
P2.5/BCLK0	54
$\overline{\text{CTS0}}$	51
P2.0/RXD1	57
P2.1/TXD1	58
P2.2/BCLK1	59
P2.3/SINT1	55
P2.4/$\overline{\text{CTS1}}$	56
P2.6	50
P2.7	49

Table 5. PLCC Package Locations with Pin Name

Location	Name
1	V_{CC}
2	V_{SS}
3	$\overline{ERROR}$
4	$\overline{RD}$
5	$\overline{WR}$
6	ALE
7	$\overline{BHE}$
8	$\overline{S2}$
9	$\overline{S1}$
10	$\overline{S0}$
11	$\overline{DEN}$
12	HLDA
13	HOLD
14	$\overline{TEST}$/BUSY
15	$\overline{LOCK}$
16	DT/$\overline{R}$
17	NMI
18	READY
19	P1.7/$\overline{GCS7}$
20	P1.6/$\overline{GCS6}$
21	P1.5/$\overline{GCS5}$

Location	Name
22	V_{SS}
23	V_{CC}
24	P1.4/$\overline{GCS4}$
25	P1.3/$\overline{GCS3}$
26	P1.2/$\overline{GCS2}$
27	P1.1/$\overline{GCS1}$
28	P1.0/$\overline{GCS0}$
29	$\overline{LCS}$
30	$\overline{UCS}$
31	INT0
32	INT1
33	INT2/$\overline{INTA0}$
34	INT3/$\overline{INTA1}$
35	INT4
36	PDTMR
37	$\overline{RESIN}$
38	RESOUT
39	PEREQ
40	OSCOUT
41	CLKIN
42	V_{CC}

Location	Name
43	V_{SS}
44	CLKOUT
45	T0OUT
46	T0IN
47	T1OUT
48	T1IN
49	P2.7
50	P2.6
51	$\overline{CTS0}$
52	TXD0
53	RXD0
54	P2.5/BCLK0
55	P2.3/SINT1
56	P2.4/$\overline{CTS1}$
57	P2.0/RXD1
58	P2.1/TXD1
59	P2.2/BCLK1
60	$\overline{NCS}$
61	AD0
62	AD8
63	V_{SS}

Location	Name
64	V_{CC}
65	V_{SS}
66	AD1
67	AD9
68	AD2
69	AD10
70	AD3
71	AD11
72	AD4
73	AD12
74	AD5
75	AD13
76	AD6
77	AD14
78	AD7
79	AD15
80	A16
81	A17
82	A18
83	A19/$\overline{ONCE}$
84	V_{SS}

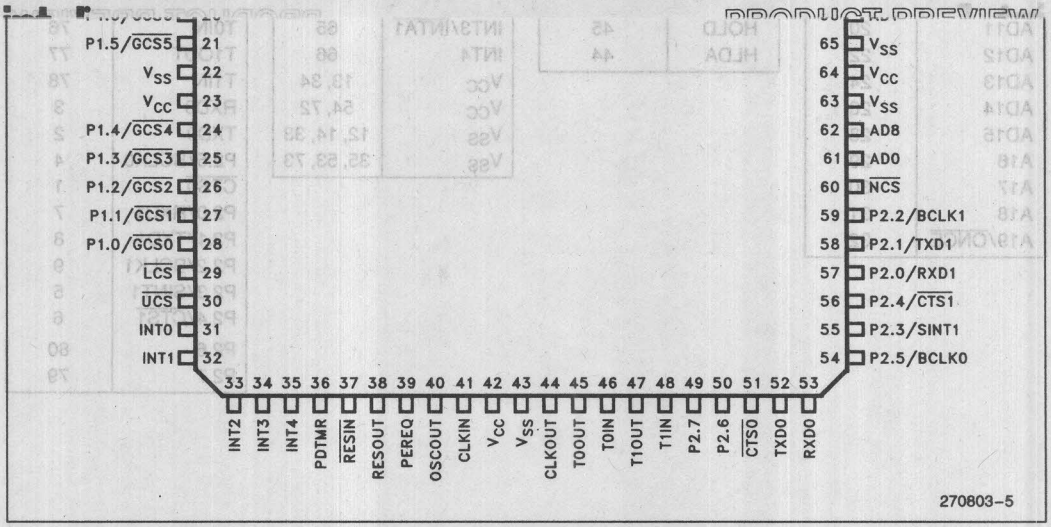


Figure 7. 84-Pin Plastic Leaded Chip Carrier Pinout Diagram

AD8	11
AD9	16
AD10	18
AD11	20
AD12	22
AD13	24
AD14	26
AD15	28
A16	29
A17	30
A18	31
A19/$\overline{\text{ONCE}}$	32

$\overline{\text{DEN}}$	43
$\overline{\text{LOCK}}$	47
HOLD	45
HLDA	44

INT0	62
INT1	63
INT2/$\overline{\text{INTA0}}$	64
INT3/$\overline{\text{INTA1}}$	65
INT4	66
V_{CC}	13, 34
V_{CC}	54, 72
V_{SS}	12, 14, 33
V_{SS}	35, 53, 73

P1.6/$\overline{\text{GCS6}}$	51
P1.7/$\overline{\text{GCS7}}$	50
T0OUT	75
T0IN	76
T1OUT	77
T1IN	78
RXD0	3
TXD0	2
P2.5/BCLK0	4
$\overline{\text{CTS0}}$	1
P2.0/RXD1	7
P2.1/TXD1	8
P2.2/BCLK1	9
P2.3/SINT1	5
P2.4/$\overline{\text{CTS1}}$	6
P2.6	80
P2.7	79

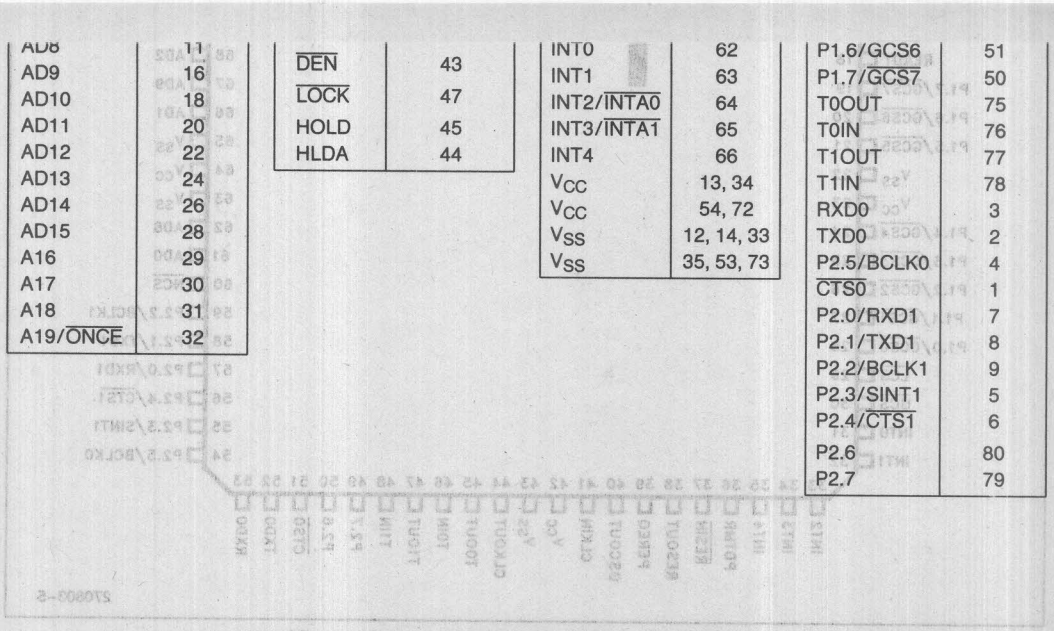


Table 7. QFP Package Location with Pin Names

Location	Name	Location	Name	Location	Name	Location	Name
1	$\overline{CTS0}$	21	AD4	41	$\overline{S1}$	61	$\overline{UCS}$
2	TXD0	22	AD12	42	$\overline{S0}$	62	INT0
3	RXD0	23	AD5	43	$\overline{DEN}$	63	INT1
4	P2.5/BCLK0	24	AD13	44	HLDA	64	INT2/$\overline{INTA0}$
5	P2.3/SINT1	25	AD6	45	HOLD	65	INT3/$\overline{INTA1}$
6	P2.4/$\overline{CTS1}$	26	AD14	46	$\overline{TEST}$	66	INT4
7	P2.0/RXD1	27	AD7	47	$\overline{LOCK}$	67	PDTMR
8	P2.1/TXD1	28	AD15	48	NMI	68	$\overline{RESIN}$
9	P2.2/BCLK1	29	A16	49	READY	69	RESOUT
10	AD0	30	A17	50	P1.7/$\overline{GCS7}$	70	OSCOUT
11	AD8	31	A18	51	P1.6/$\overline{GCS6}$	71	CLKIN
12	V_{SS}	32	A19/$\overline{ONCE}$	52	P1.5/$\overline{GCS5}$	72	V_{CC}
13	V_{CC}	33	V_{SS}	53	V_{SS}	73	V_{SS}
14	V_{SS}	34	V_{CC}	54	V_{CC}	74	CLKOUT
15	AD1	35	V_{SS}	55	P1.4/$\overline{GCS4}$	75	T0OUT
16	AD9	36	$\overline{RD}$	56	P1.3/$\overline{GCS3}$	76	T0IN
17	AD2	37	$\overline{WR}$	57	P1.2/$\overline{GCS2}$	77	T1OUT
18	AD10	38	ALE	58	P1.1/$\overline{GCS1}$	78	T1IN
19	AD3	39	$\overline{BHE}$	59	P1.0/$\overline{GCS0}$	79	P2.7
20	AD11	40	$\overline{S2}$	60	$\overline{LCS}$	80	P2.6

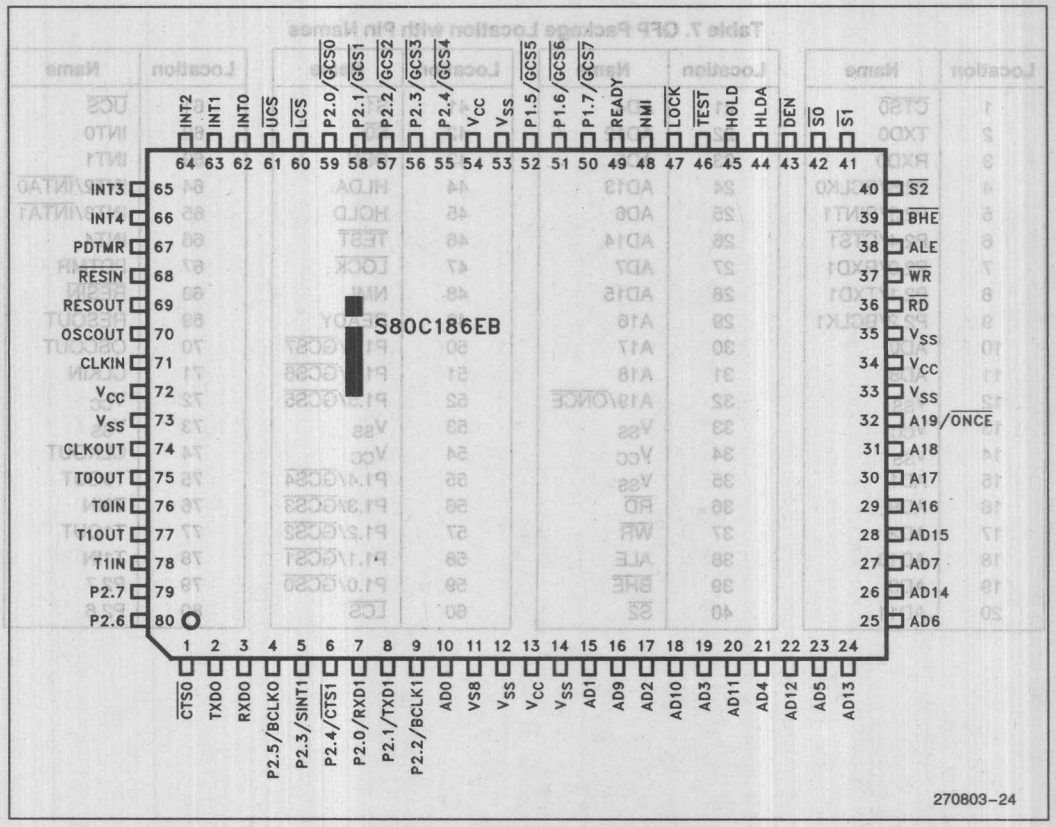


Figure 8. Quad Flat Pack Pinout Diagram

ent) with the following equation:

$$T_A = T_C - P^*\theta_{CA}$$

Table 8. Thermal Resistance (θ_{CA}) at Various Airflows (in °C/Watt)

	Airflow ft/min (m/sec)					
	0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
θ_{CA} (PLCC)	30	24	21	19	17	16.5
θ_{CA} (QFP)	58	47	43	40	38	36

Table 9. Maximum T_A at Various Airflows (in °C)

		Airflow ft/min (m/sec)					
	T_F (MHz)	0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
T_A (PLCC)	16	91.5	93.5	94	94.5	95.5	95.5
	26	88.5	91	92	92.5	93.5	93.5
	32	85	87.5	89.5	90.5	91.5	92
T_A (QFP)	16	98	101	102	103	103.5	104
	26	92	96	97.5	99	99.5	100
	32	85	90.5	92.5	94	95	96

ELECTRICAL SPECIFICATIONS

NOTICE: This document contains information on products in the design phase of development. Do not finalize a design with this information. Revised information will be published when the product is available.

Absolute Maximum Ratings

Parameter	Maximum Rating
Storage Temperature	−65°C to +150°C
Case Temp Under Bias	−65°C to +120°C
Supply Voltage wrt V_{SS}	−0.5V to +6.5V
Voltage on other Pins wrt. V_{SS}	−0.5V to V_{CC} +0.5V

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

The data present in this document are provided as a PREVIEW of expected device performance. Since Intel currently does not produce a product that complies with these specifications, this data sheet should not be used as the basis for a final design. Once information corresponding to an actual device is available, an ADVANCED INFORMATION data sheet will be published to supercede this document.

OPERATING CONDITIONS

Symbol	Parameter	Min	Max	Units
V_{CC}	Supply Voltage	4.5	5.5	V
T_F	Input Clock Frequency			
	80C186EB-16	0	32	MHz
	80C186EB-13	0	26.08	MHz
	80C186EB	0	16	MHz
T_C	Case Temperature Under Bias			
	N80C186EB-XX (PLCC)	−40	+100	°C
	S80C186EB-XX (QFP)	−40	+114	°C

RECOMMENDED CONNECTIONS

Power and ground connections must be made to multiple V_{CC} and V_{SS} pins. Every 80C186EB-based circuit board should include separate power (V_{CC}) and ground (V_{SS}) planes. Every V_{CC} pin must be connected to the power plane, and every V_{SS} pin must be connected to the ground plane. Pins identified as "NC" must not be connected in the system. Liberal decoupling capacitance should be placed near the 80C186EB. The processor can cause transient power surges when its output buffers transition, particularly when connected to large capacitive loads.

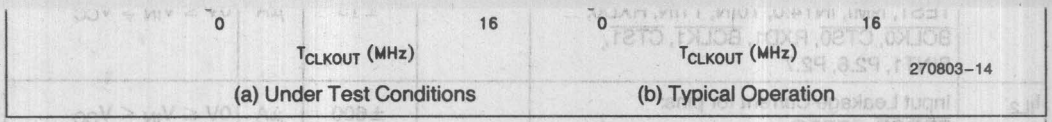
Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance is reduced by placing the decoupling capacitors as close as possible to the 80C186EB V_{CC} and V_{SS} package pins.

Always connect any unused input to an appropriate signal level. In particular, unused interrupt inputs (NMI, INT0:4) should be connected to V_{CC} through a pull-up resistor (in the range of 100 KΩ). **Leave any unused output pin or any NC pin unconnected.**

TARGETED D.C. SPECIFICATIONS

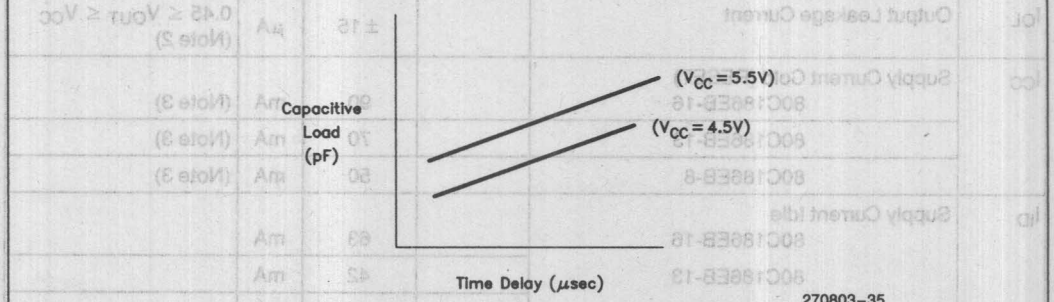
Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage for all pins except $\overline{RESIN}$	−0.5	0.3*V_{CC}	V	
V_{IH}	Input High Voltage for all pins except $\overline{RESIN}$	0.7*V_{CC}	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 3 mA (Min)
V_{OH}	Output High Voltage	V_{CC} − 0.5		V	I_{OH} = −2 mA (Mln)
V_{HYR}	Input Hysterisis on $\overline{RESIN}$	0.65		V	
I_{IL1}	Input Leakage Current for pins: AD15:0, READY, HOLD, $\overline{RESIN}$, CLKIN, $\overline{TEST}$, NMI, INT4:0, T0IN, T1IN, RXD0, $\overline{BCLK0}$, $\overline{CTS0}$, RXD1, $\overline{BCLK1}$, $\overline{CTS1}$, SINT1, P2.6, P2.7		±15	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{IL2}	Input Leakage Current for pins: $\overline{ERROR}$, PEREQ		±600	μA	0V ≤ V_{IN} < V_{CC}
I_{IL3}	Input Leakage Current for pins: A19/$\overline{ONCE}$, A18:16, $\overline{LOCK}$		−2	mA	V_{IN} = 0.7 V_{CC} (Note 1)
I_{OL}	Output Leakage Current		±15	μA	0.45 ≤ V_{OUT} ≤ V_{CC} (Note 2)
I_{CC}	Supply Current Cold (RESET) 80C186EB-16		90	mA	(Note 3)
	80C186EB-13		70	mA	(Note 3)
	80C186EB-8		50	mA	(Note 3)
I_{ID}	Supply Current Idle 80C186EB-16		63	mA	
	80C186EB-13		42	mA	
	80C186EB-8		35	mA	
I_{PD}	Supply Current Powerdown 80C186EB-16		100	μA	
	80C186EB-13		100	μA	
	80C186EB-8		100	μA	
CIN	Input Pin Capacitance	0	15	pF	T_F = 1 MHz
COUT	Output Pin Capacitance	0	15	pF	T_F = 1 MHz (Note 4)

NOTES:
1. These pins have an internal pull-up resistor that is active while $\overline{RESIN}$ is low and ONCE Mode is not active.
2. Output pins being floated during HOLD or by invoking the ONCE Mode.
3. Measured at worst case frequency, V_{CC}, and temperature with all outputs loaded as specified in A.C. Test Conditions, and the $\overline{RESIN}$ pin held low.
4. Output capacitance is the capacitive load of a floating output pin.



(a) Under Test Conditions (b) Typical Operation

PDTMR PIN CAPACITANCE CHART



Typical Startup Delay (Room Temp.)

OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	20	ns	1, 4
T	CLKOUT Period		2*T_C	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{BHE}$, $\overline{LOCK}$, A19:16	3	22	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{NCS}$, $\overline{RD}$, $\overline{WR}$	3	27	ns	1, 4, 6, 8
T_{CLOV1}	$\overline{BHE}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:16	3	22	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, AD15:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	27	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{BHE}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:16	0	25	ns	1
T_{CLOF}	$\overline{DEN}$, AD15:0	0	25	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	AD15:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, AD15:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$, PEREQ, $\overline{ERROR}$	10		ns	1, 9
T_{CLIH}	HOLD, PEREQ, $\overline{ERROR}$	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{BHE}$, $\overline{LOCK}$ and A19:16 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C186EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED A.C. Characteristics—80C186EB-13

Symbol	Parameter	TARGET Min	TARGET Max	Units	Notes
INPUT CLOCK					
T_F	CLKIN Frequency	0	26.08	MHz	1
T_C	CLKIN Period	38.34	∞	ns	1
T_{CH}	CLKIN High Time	12	∞	ns	1, 2
T_{CL}	CLKIN Low Time	12	∞	ns	1, 2
T_{CR}	CLKIN Rise Time	1	8	ns	1, 3
T_{CF}	CLKIN Fall Time	1	8	ns	1, 3
OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	23	ns	1, 4
T	CLKOUT Period		2*T_C	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{BHE}$, $\overline{LOCK}$, A19:16	3	25	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{NCS}$, $\overline{RD}$, $\overline{WR}$	3	30	ns	1, 4, 6, 8
T_{CLOV1}	$\overline{BHE}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:16	3	25	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, AD15:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	30	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{BHE}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:16	0	25	ns	1
T_{CLOF}	$\overline{DEN}$, AD15:0	0	25	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	AD15:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, AD15:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$, PEREQ, $\overline{ERROR}$	10		ns	1, 9
T_{CLIH}	HOLD, PEREQ, $\overline{ERROR}$	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{BHE}$, $\overline{LOCK}$ and A19:16 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C186EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED A.C. Characteristics—80C186EB-8

Symbol	Parameter	TARGET Min	TARGET Max	Units	Notes
INPUT CLOCK					
T_F	CLKIN Frequency	0	16	MHz	1
T_C	CLKIN Period	62.5	∞	ns	1
T_{CH}	CLKIN High Time	15	∞	ns	1, 2
T_{CL}	CLKIN Low Time	15	∞	ns	1, 2
T_{CR}	CLKIN Rise Time	1	8	ns	1, 3
T_{CF}	CLKIN Fall Time	1	8	ns	1, 3
OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	27	ns	1, 4
T	CLKOUT Period		2*T_C	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{BHE}$, $\overline{LOCK}$, A19:16	3	30	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{NCS}$, $\overline{RD}$, $\overline{WR}$	3	35	ns	1, 4, 6, 7
T_{CLOV1}	$\overline{BHE}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:16	3	30	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, AD15:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	35	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{BHE}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:16	0	30	ns	1
T_{CLOF}	$\overline{DEN}$, AD15:0	0	35	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	AD15:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, AD15:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$, PEREQ, $\overline{ERROR}$	10		ns	1, 9
T_{CLIH}	HOLD, PEREQ, $\overline{ERROR}$	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{BHE}$, $\overline{LOCK}$ and A19:16 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C186EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED Relative Timings (80C186EB-16, -13, -8)

Symbol	Parameter	TARGET Min	TARGET Max	Unit	Notes
RELATIVE TIMINGS					
T_{LHLL}	ALE Rising to ALE Falling	T − 15		ns	
T_{AVLL}	Address Valid to ALE Falling	½T − 10		ns	
T_{PLLL}	Chip Selects Valid to ALE Falling	½T − 10		ns	1
T_{LLAX}	Address Hold from ALE Falling	½T − 10		ns	
T_{LLWL}	ALE Falling to $\overline{WR}$ Falling	½T − 15		ns	1
T_{LLRL}	ALE Falling to $\overline{RD}$ Falling	½T − 15		ns	1
T_{WHLH}	$\overline{WR}$ Rising to ALE Rising	½T − 10		ns	1
T_{AFRL}	Address Float to $\overline{RD}$ Falling	0		ns	
T_{RLRH}	$\overline{RD}$ Falling to $\overline{RD}$ Rising	(2*T) − 5		ns	2
T_{WLWH}	$\overline{WR}$ Falling to $\overline{WR}$ Rising	(2*T) − 5		ns	2
T_{RHAX}	$\overline{RD}$ Rising to Address Active	T − 15		ns	
T_{WHDX}	Output Data Hold after $\overline{WR}$ Rising	T − 15		ns	
T_{WHPH}	$\overline{WR}$ Rising to Chip Select Rising	½T − 10		ns	1
T_{RHPH}	$\overline{RD}$ Rising to Chip Select Rising	½T − 10		ns	1
T_{PHPL}	$\overline{CS}$ Active to $\overline{CS}$ Inactive	½T − 10		ns	1
T_{OVRH}	$\overline{ONCE}$ Active to $\overline{RESIN}$ Rising	½T		ns	
T_{RHOX}	$\overline{ONCE}$ Hold from $\overline{RESIN}$ Rising	½T		ns	

NOTES:
1. Assumes equal loading on both pins.
2. Can be extended using wait states.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED Serial Port Mode 0 Timings (80C186EB-16, -13, -8)

Symbol	Parameter	TARGET Min	TARGET Max	Unit	Notes
T_{XLXL}	TXD Clock Period	T + nT − 10		ns	1, 2
T_{XLXH}	TXD Clock Low to Clock High (N > 1)	2T − 10		ns	1, 2
T_{XLXH}	TXD Clock Low to Clock High (N = 1)	T − 10		ns	1, 2
T_{XHXL}	TXD Clock High to Clock Low	(N − 1) T − 10		ns	2
T_{QVXH}	RXD Output Data Setup to TXD Clock High	nT − 20		ns	1, 2
T_{XHQX}	RXD Output Data Hold after TXD Clock High	T − 20		ns	1
T_{XHQZ}	RXD Output Data Float after Last TXD Clock High		T + 20	ns	1
T_{DVXH}	RXD Input Data Setup to TXD Clock High	T + 20		ns	1
T_{XHDX}	RXD Input Data Hold after TXD Clock High	0		ns	1

NOTES:
1. See Figure 15 for waveforms.
2. n is the value of the BxCMP register ignoring the ICLK Bit (i.e., ICLK = 0).

A.C. TEST CONDITIONS

The A.C. specifications are tested with the 50 pF load shown in Figure 9. See the Derating Curves section to see how timings vary with load capacitance.

Specifications are measured at the $V_{CC}/2$ crossing point, unless otherwise specified. See A.C. Timing Waveforms, for A.C. specification definitions, test pins, and illustrations.

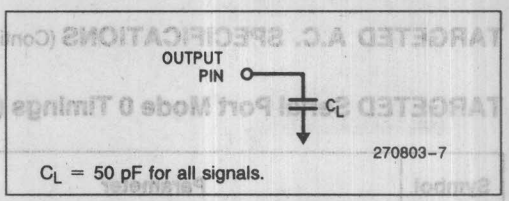


Figure 9. A.C. Test Load

A.C. TIMING WAVEFORMS

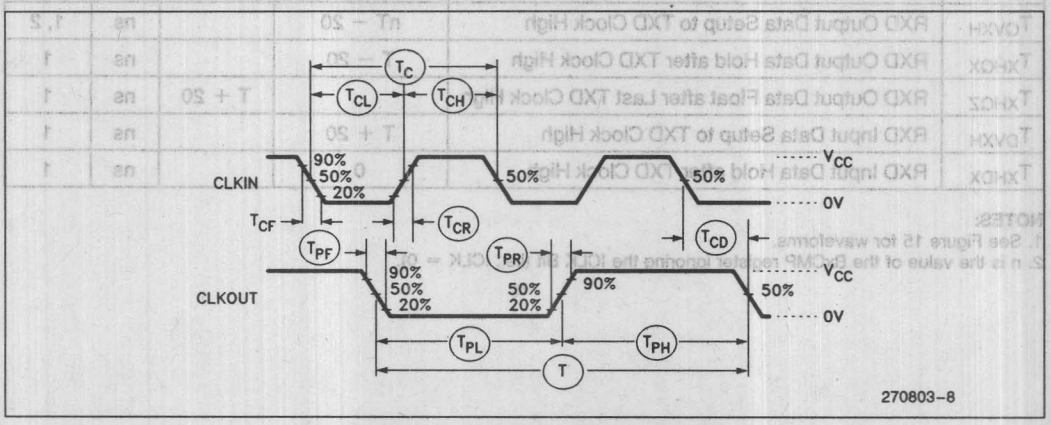


Figure 10. Input and Output Clock Waveform

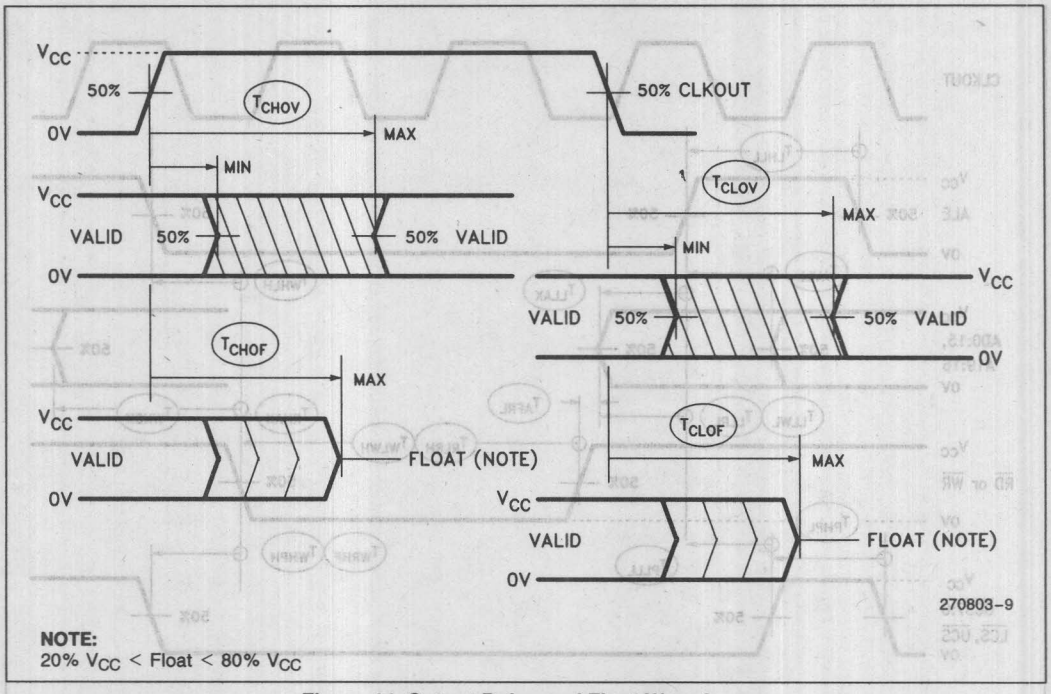


Figure 11. Output Delay and Float Waveform

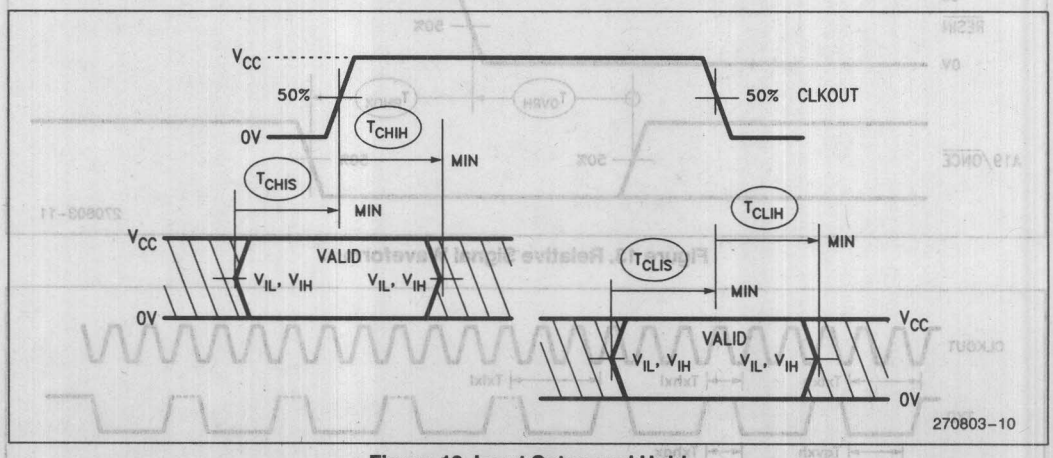


Figure 12. Input Setup and Hold

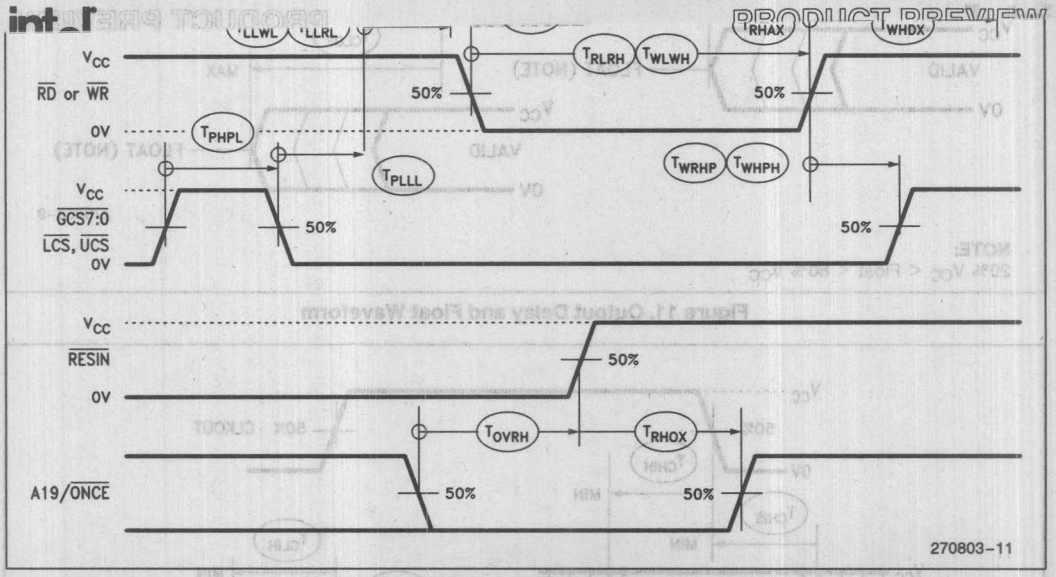


Figure 13. Relative Signal Waveform

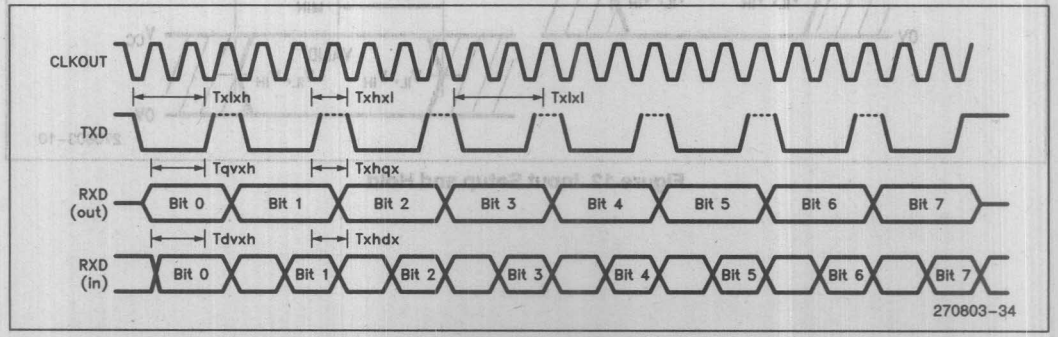


Figure 14. Serial Port Mode 0 Waveform

DERATING CURVES

OUTPUT DELAY OR HOLD VERSUS LOAD CAPACITANCE

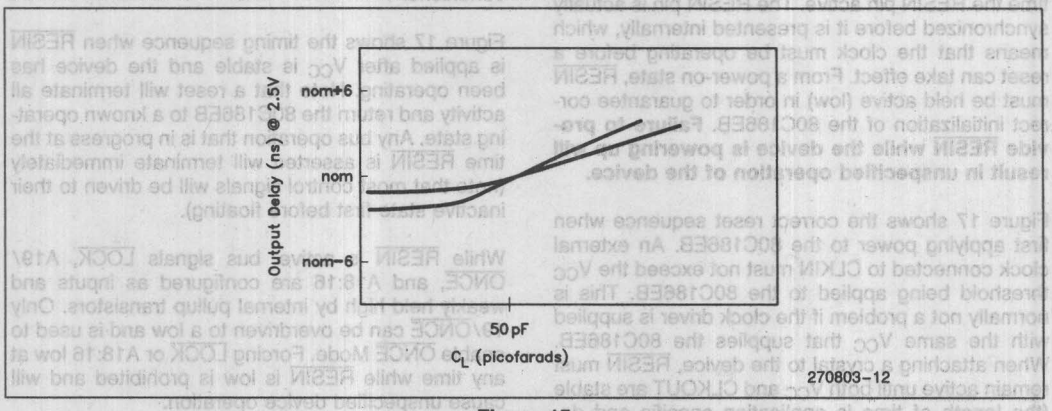


Figure 15

OUTPUT RISE OR FALL TIME VERSUS LOAD CAPACITANCE

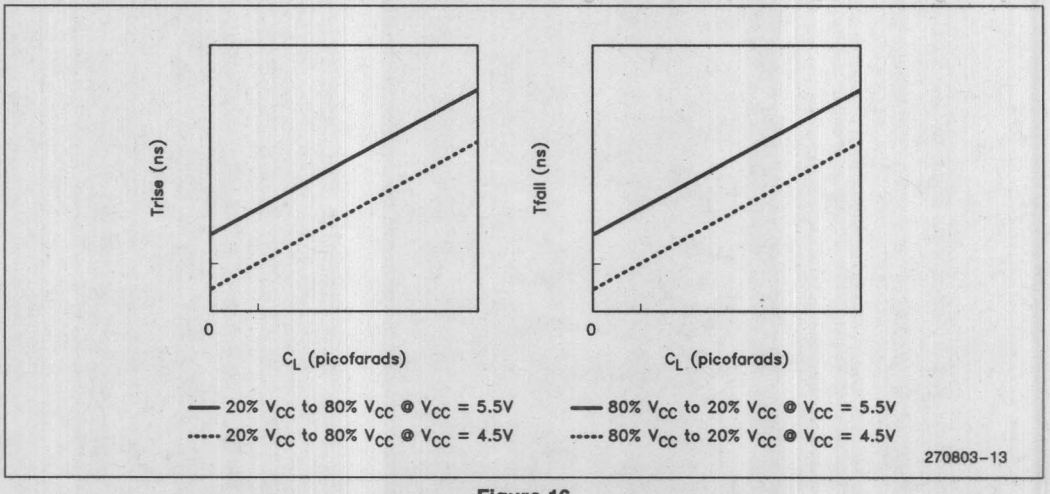


Figure 16

RESET

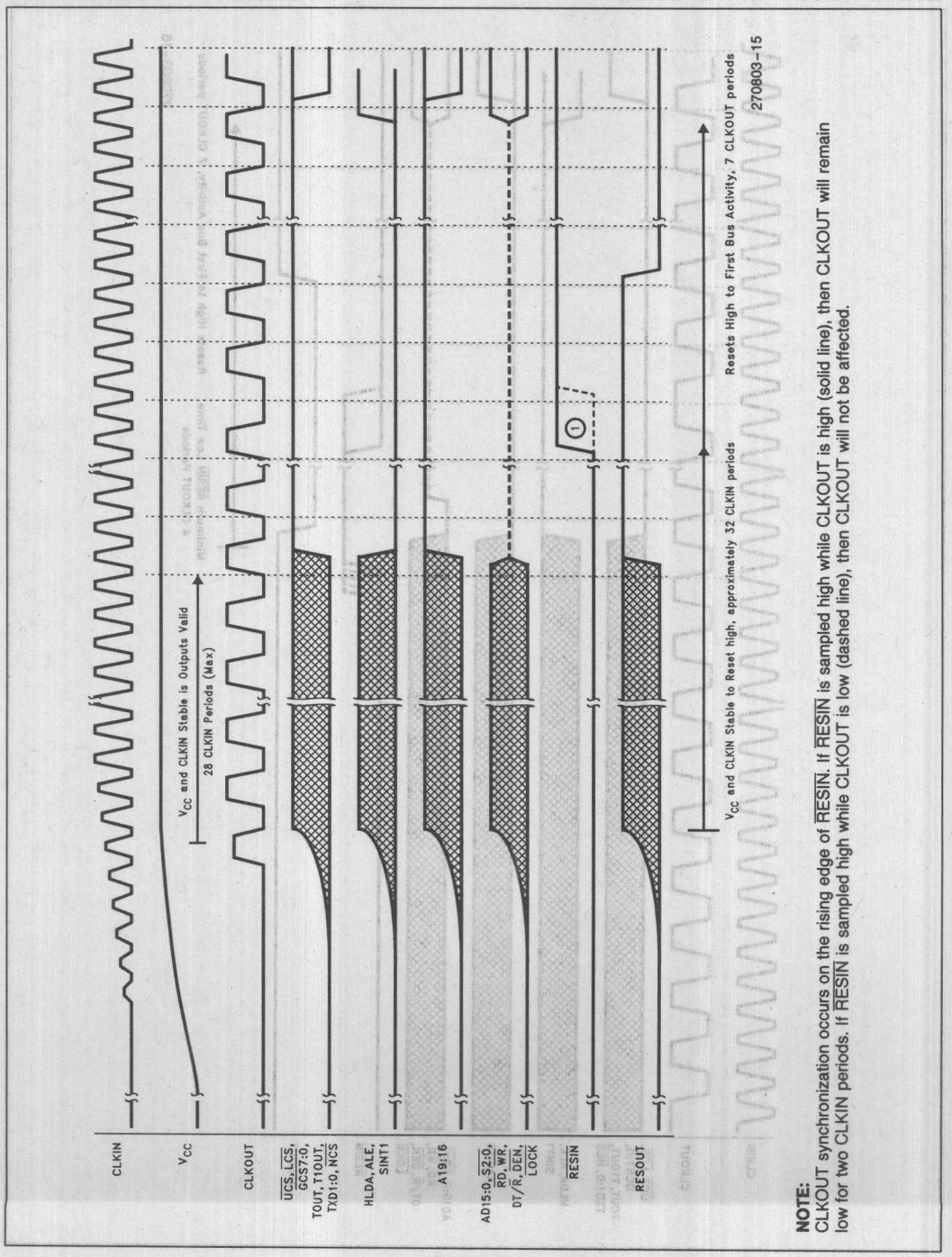
The 80C186EB will perform a reset operation any time the $\overline{RESIN}$ pin active. The $\overline{RESIN}$ pin is actually synchronized before it is presented internally, which means that the clock must be operating before a reset can take effect. From a power-on state, $\overline{RESIN}$ must be held active (low) in order to guarantee correct initialization of the 80C186EB. **Failure to provide $\overline{RESIN}$ while the device is powering up will result in unspecified operation of the device.**

Figure 17 shows the correct reset sequence when first applying power to the 80C186EB. An external clock connected to CLKIN must not exceed the V_{CC} threshold being applied to the 80C186EB. This is normally not a problem if the clock driver is supplied with the same V_{CC} that supplies the 80C186EB. When attaching a crystal to the device, $\overline{RESIN}$ must remain active until both V_{CC} and CLKOUT are stable (the length of time is application specific and depends on the startup characteristics of the crystal circuit). The $\overline{RESIN}$ pin is designed to operate correctly using an RC reset circuit, but the designer must ensure that the ramp time for V_{CC} is not so long that $\overline{RESIN}$ is never really sampled at a logic low level when V_{CC} reaches minimum operating conditions.

Figure 17 shows the timing sequence when $\overline{RESIN}$ is applied after V_{CC} is stable and the device has been operating. Note that a reset will terminate all activity and return the 80C186EB to a known operating state. Any bus operation that is in progress at the time $\overline{RESIN}$ is asserted will terminate immediately (note that most control signals will be driven to their inactive state first before floating).

While $\overline{RESIN}$ is active, bus signals $\overline{LOCK}$, A19/$\overline{ONCE}$, and A18:16 are configured as inputs and weakly held high by internal pullup transistors. Only 19/$\overline{ONCE}$ can be overdriven to a low and is used to enable $\overline{ONCE}$ Mode. Forcing $\overline{LOCK}$ or A18:16 low at any time while $\overline{RESIN}$ is low is prohibited and will cause unspecified device operation.

COLD RESET WAVEFORMS



NOTE:
CLKOUT synchronization occurs on the rising edge of $\overline{RESIN}$. If $\overline{RESIN}$ is sampled high while CLKOUT is high (solid line), then CLKOUT will remain low for two CLKIN periods. If $\overline{RESIN}$ is sampled high while CLKOUT is low (dashed line), then CLKOUT will not be affected.

Figure 17

WARM RESET WAVEFORMS

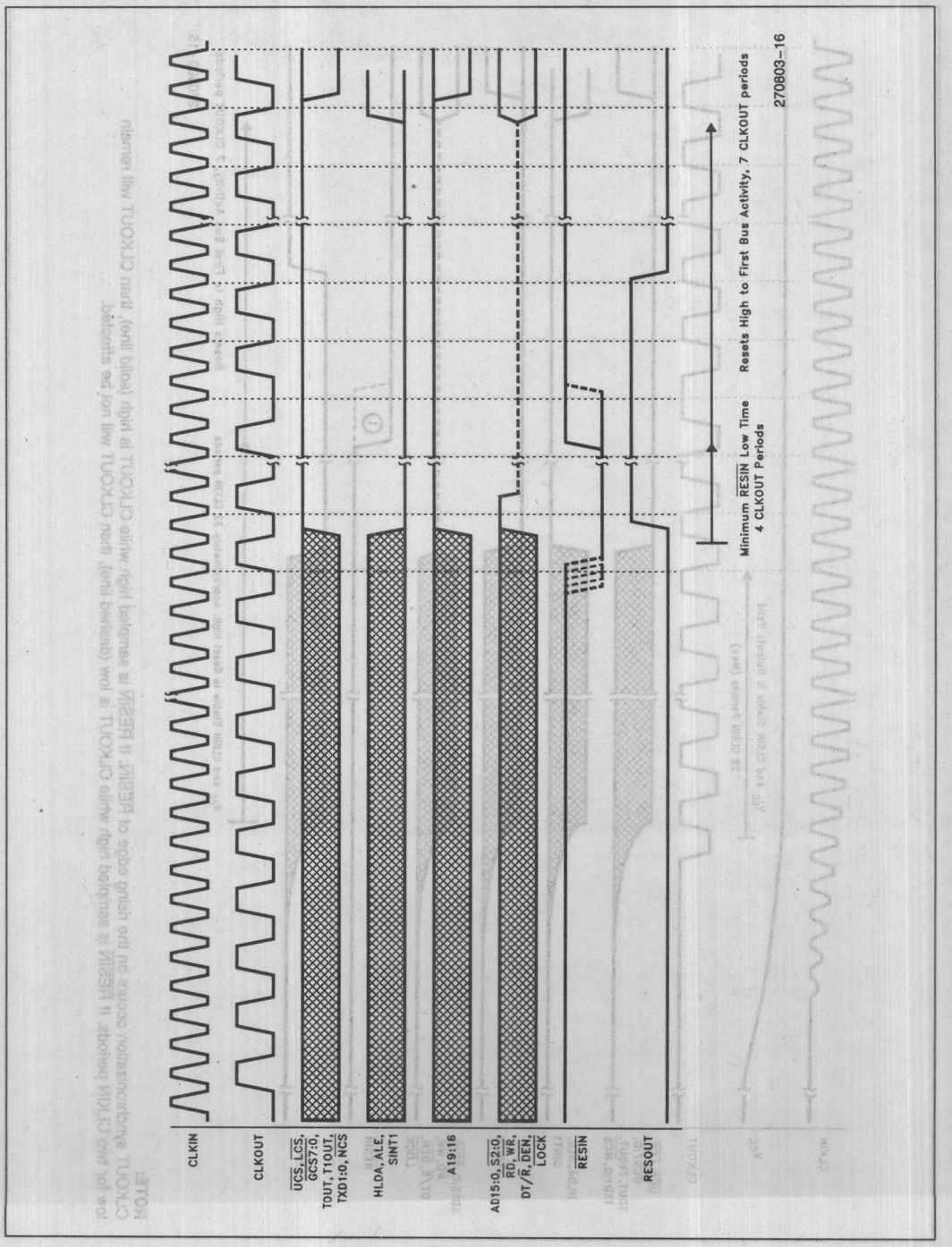


Figure 18

BUS CYCLE WAVEFORMS

Figures 20 through 26 present the various bus cycles that are generated by the 80C186EB. What is shown in the figure is the relationship of the various bus signals to CLKOUT. These figures along with the information present in **A.C. Specifications** allow the user to determine all the critical timing analysis needed for a given application.

Figure 19 shows the 80C186EB bus state diagram. Typically a bus cycle will consist of four consecutive states labeled T1, T2, T3, and T4. A TI state exists when no bus cycle is pending. A TI state can occur if the pre-fetch queue is full, the BIU is waiting for the completion of an effective address calculation, or the BIU is told to wait for a pending EU bus operation. The latter case will occur most often during the sequencing of an interrupt acknowledge or during the execution of numerics escape instructions.

Aside from TI states, multiple T3 states can occur during a bus cycle if READY is not returned in time (or the CSU has been programmed to automatically insert wait-states). A T3 state will be followed by either a T4 state (if a bus cycle is pending), or a TI state (if no bus cycle is pending). Only multiple T3 or TI states can exist (i.e., there is no way to extend the T1, T2, or T4 states).

Figures 20 and 21 present a typical bus read and write operation respectively. Bus read operations include memory, I/O, instruction fetch, and refresh bus cycles. Bus write operations include memory and I/O bus cycles. The only variation among the different bus cycles would be the range of address generated and the state of the status signals.

The Halt bus cycle is shown in Figure 22. Note that the condition of the AD15:0 pin can be either floating or driving depending on the operation of the bus cycle that preceded the Halt. The pins will float if the previous bus cycle was a read, otherwise they will drive. None of the control signals (e.g., $\overline{RD}$, $\overline{WR}$, $\overline{DEN}$, etc.) will be activated, however.

Figure 21 shows the sequence of bus cycles run when an interrupt is acknowledged and the ICU has been programmed for Cascade Mode. Note the address information is not valid for the two bus cycles run, however, also note that $\overline{RD}$ and $\overline{WR}$ are not generated. Vector information needs to be returned during the second bus cycle.

Figures 24 and 25 present the operation of bus HOLD. Figure 24 shows how bus HOLD is entered and exited under normal operating conditions. Figure 25 shows the effect specific bus signals have when a refresh bus cycle request has been generated and the bus is currently unavailable due to a bus HOLD.

The effects of READY on bus operation is shown in Figure 26. READY is useful in extending the bus cycle to meet the various access requirements for memory and peripheral devices in the system. Additional T3 states added to the bus cycle have been appropriately labeled Tw.

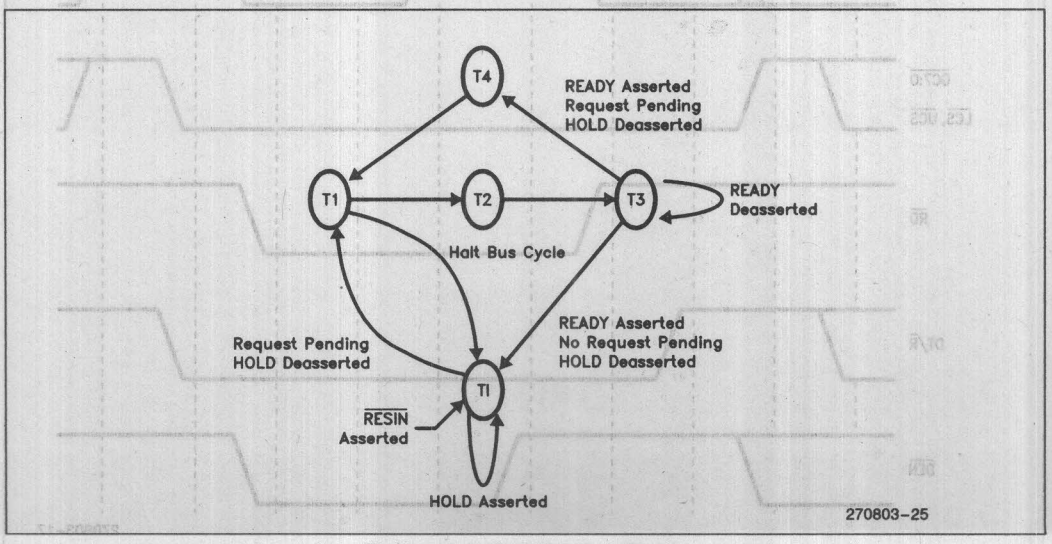


Figure 19. 80C186EB Bus States

BUS CYCLE WAVEFORMS

MEMORY READ, I/O READ, INSTRUCTION FETCH, AND REFRESH WAVEFORM

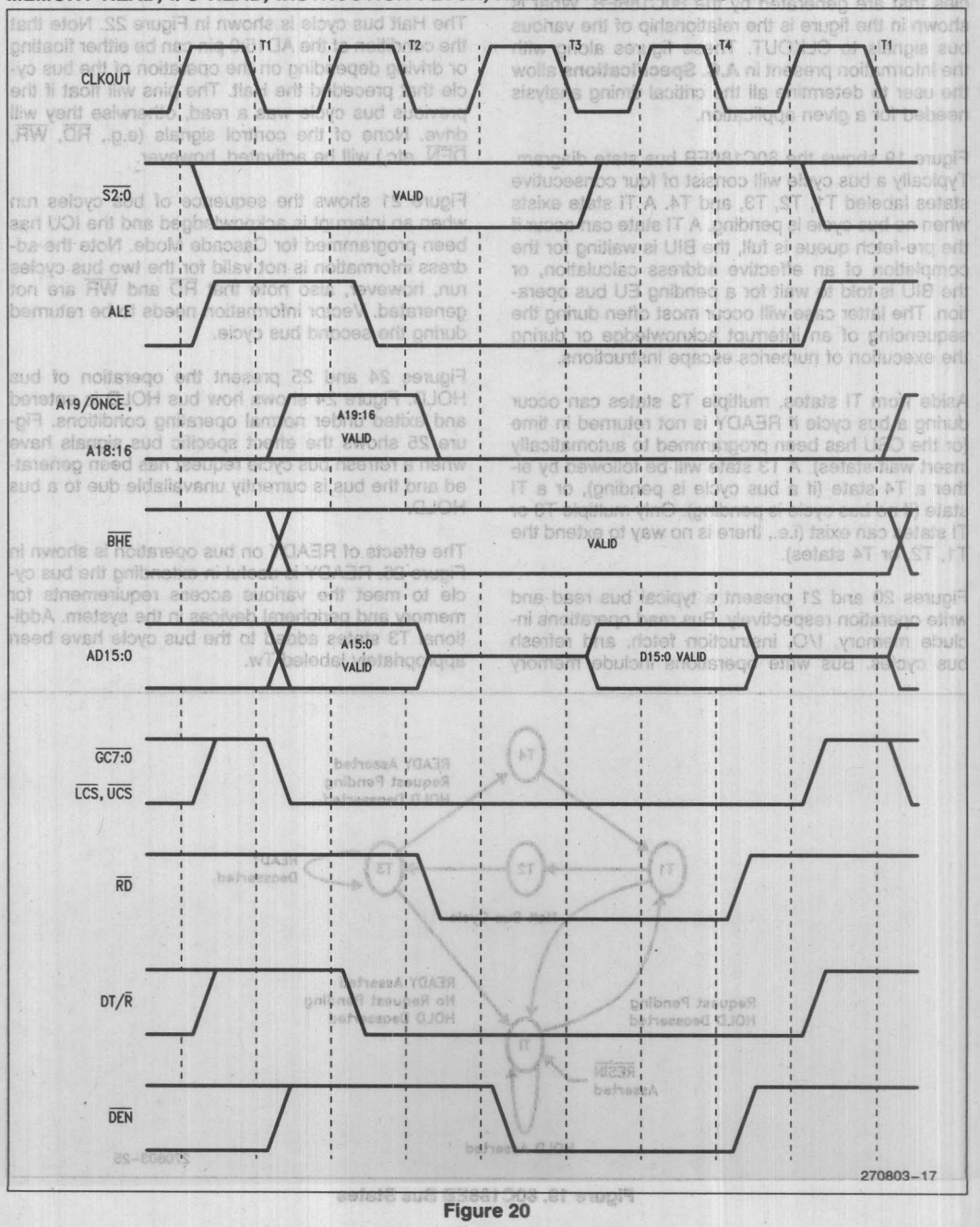


Figure 20

MEMORY WRITE AND I/O WRITE CYCLE WAVEFORM

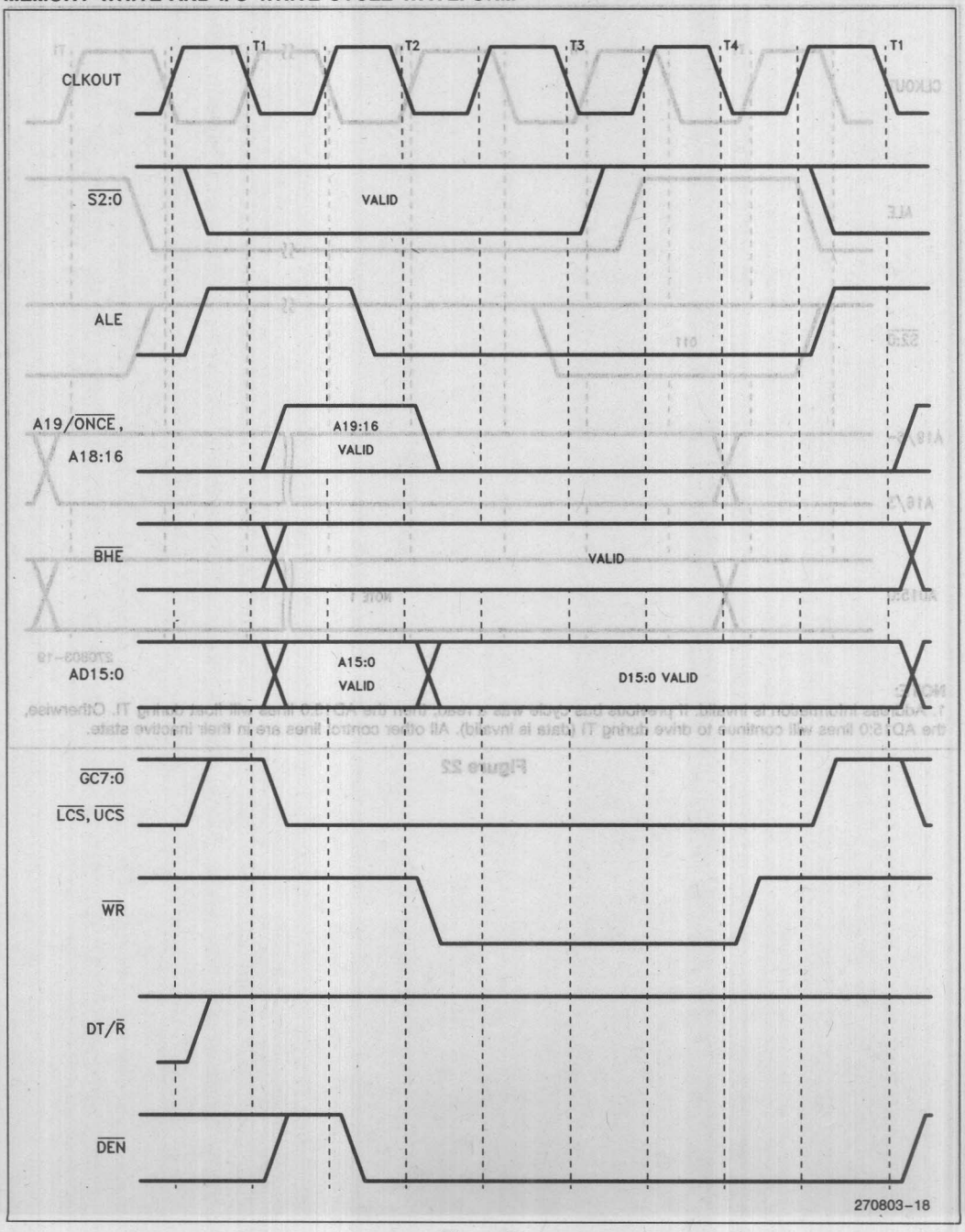
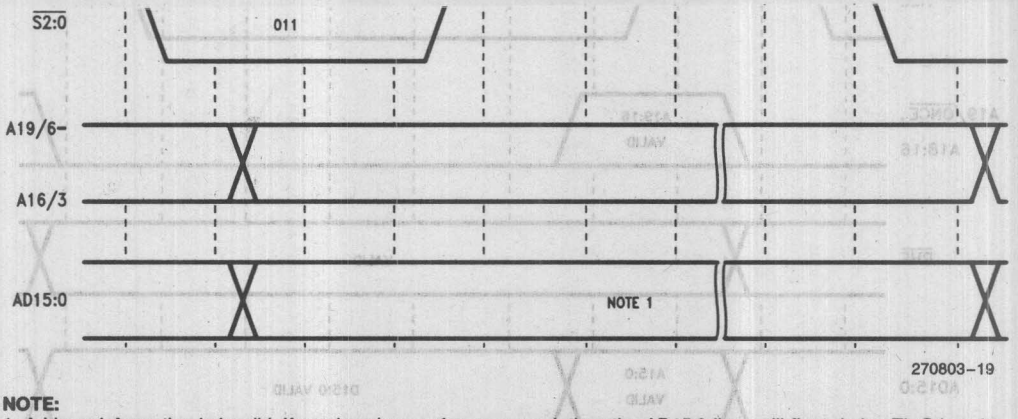


Figure 21



NOTE:
1. Address information is invalid. If previous bus cycle was a read, then the AD15:0 lines will float during TI. Otherwise, the AD15:0 lines will continue to drive during TI (data is invalid). All other control lines are in their inactive state.

Figure 22

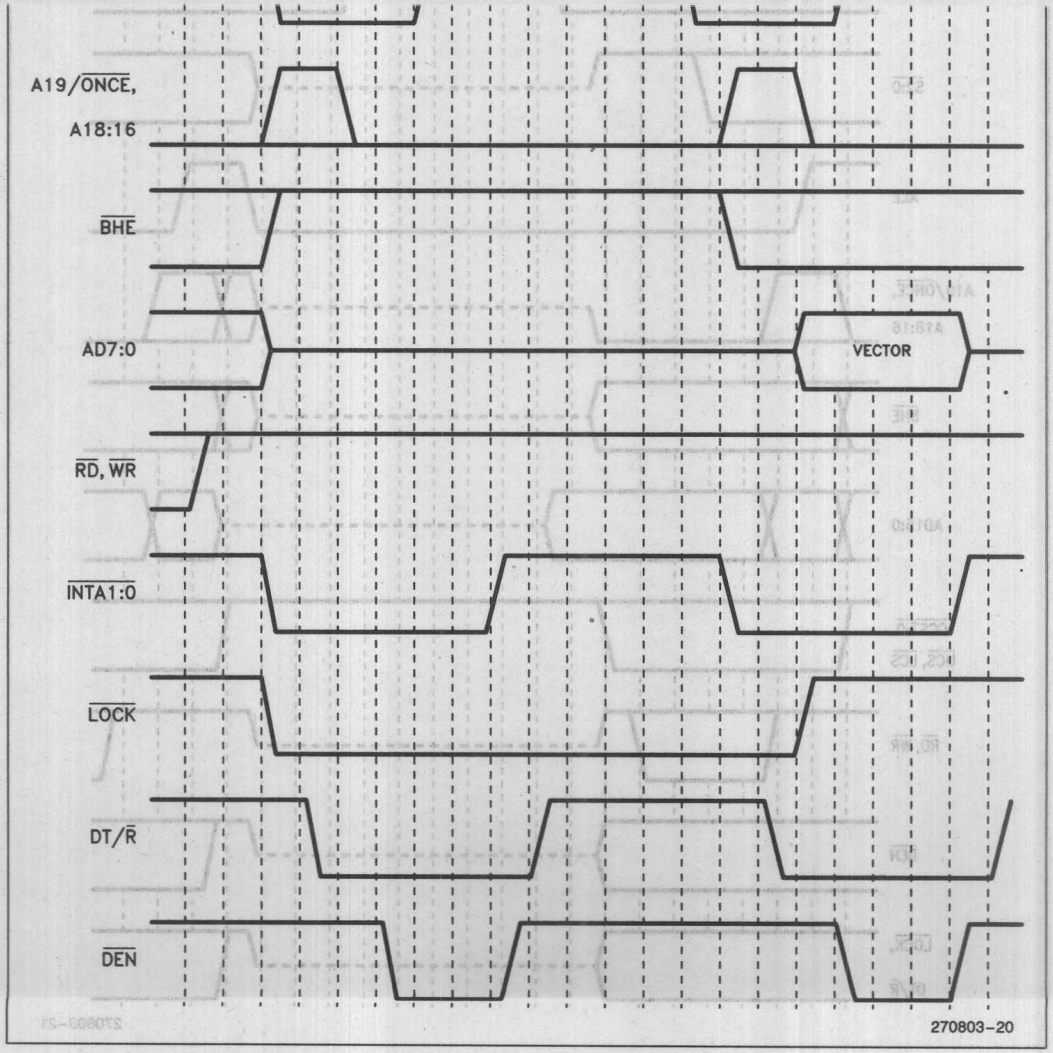

A19/ONCE,
A18:16
BHE
AD7:0
VECTOR
RD, WR
INTA1:0
LOCK
DT/R
DEN
270803-20

Figure 23

HOLD/HLDA CYCLE WAVEFORMS

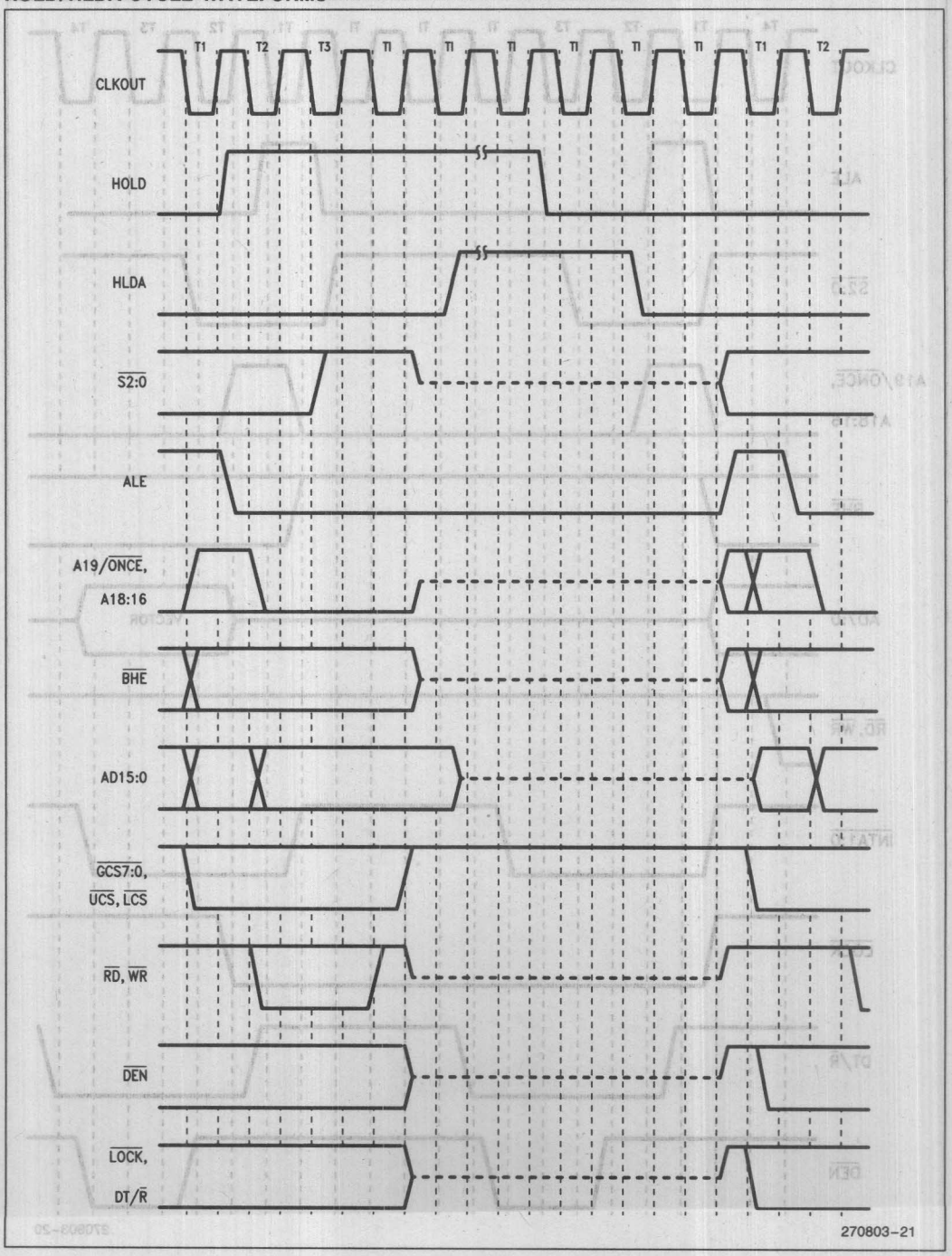
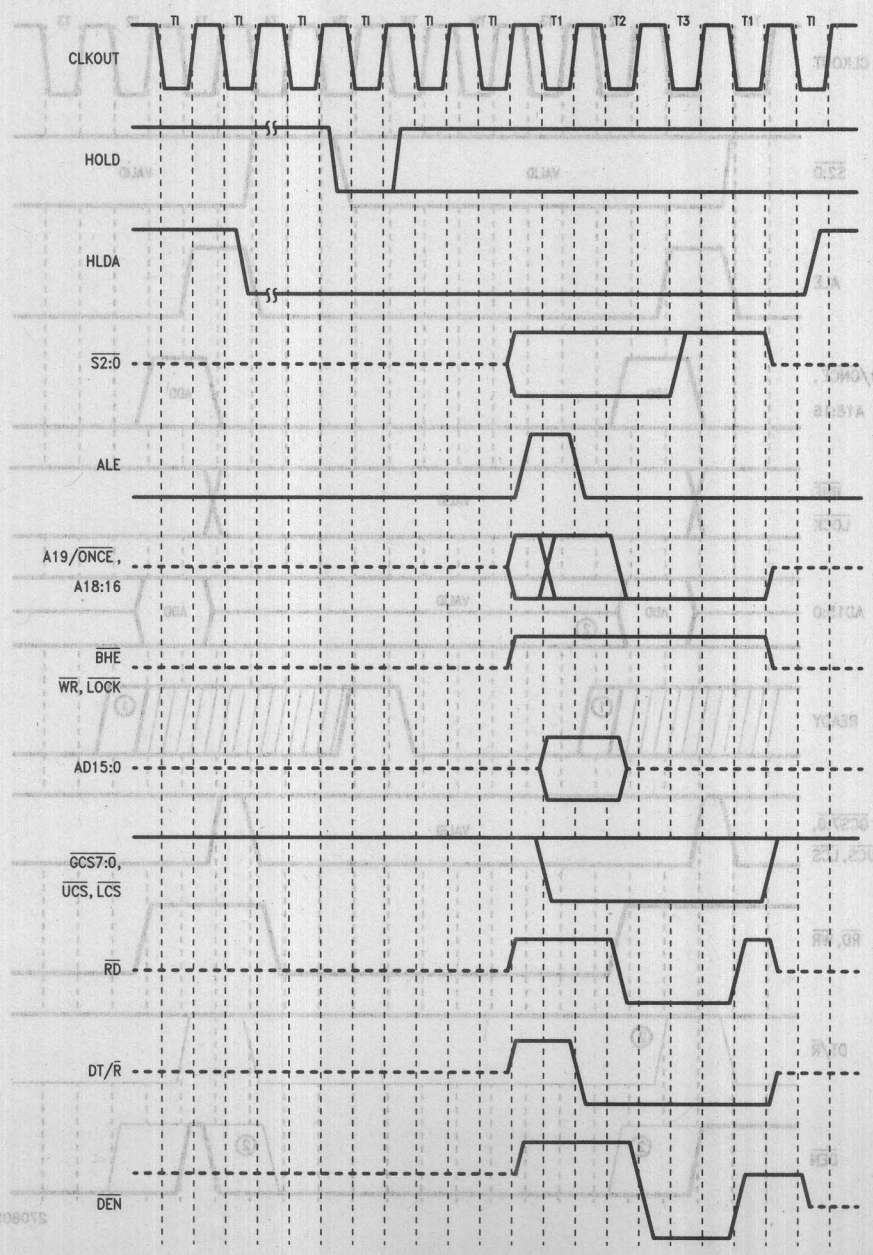


Figure 24

REFRESH DURING HLDA CYCLE WAVEFORM

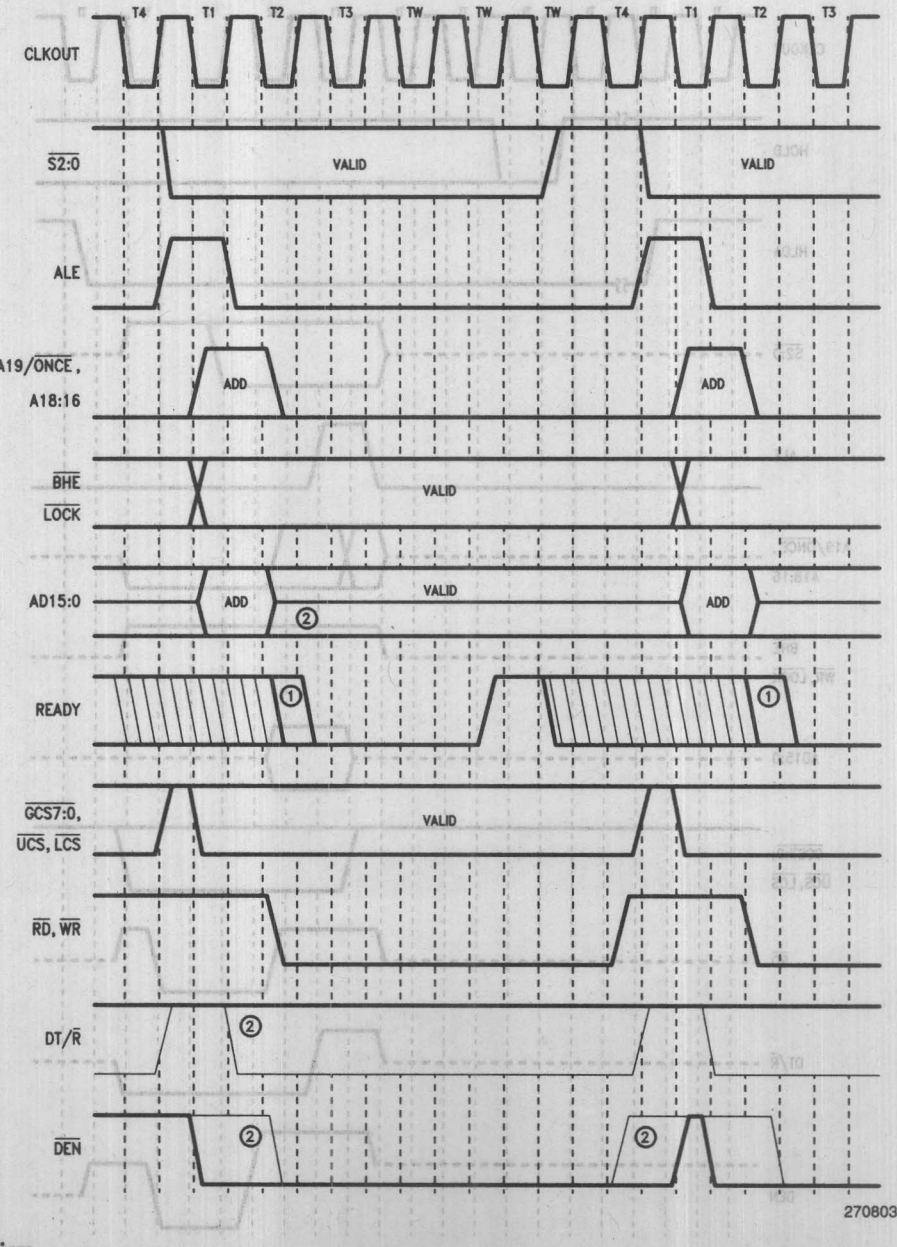


270803-22

NOTES:
1. READY must be low by either edge to cause a wait state.
2. Lighter lines indicate READ cycles, darker lines indicate WRITE cycles.

Figure 25

READY CYCLE WAVEFORM



NOTES:
1. READY must be low by either edge to cause a wait state.
2. Lighter lines indicate READ cycles, darker lines indicate WRITE cycles.

Figure 26

Not all defined register bits can be read and/or written, although most registers are read/write. Some registers, like the P1DIR register, exist but do not have any effect on the operation of the 80C186EB. For example, the Port1 pins are output only and cannot be changed by programming the P1DIR register. However, the P1DIR register can still be read and written—which allows the P1DIR register to be used as a temporary 8-bit data register.

Reads and writes to any of the PCB registers will cause a bus cycle to be run externally, however, none of the chip selects will go active (even if they overlap the PCB address range). Data read back from the AD15:0 bus is ignored, and all cycles will take zero wait states (except accesses to the Timer/Counter registers which take one wait state due to internal synchronization).

Figures 27 and 28 present the registers associated with the Interrupt Control Unit (ICU). A write to the MASK (08H) register will also effect the corresponding MSK bit in each of the control registers (e.g., setting the TMR bit in the MASK register will also set the MSK bit in the TMRCON register).

wise (like the P1DIR register), the registers can be thought of being an 8-bit data register.

Figure 31 presents the register bit definitions of the Serial Communications Unit (SCU). The transmit and receive buffer registers are both readable and writeable. Note that a read from SxSTS register will clear all of the status information (except for CTS, which actually is derived from the pin itself).

The Chip-Select Unit (CSU) registers are presented in Figure 33 and the Refresh Control Unit (RCU) registers are presented in Figure 32. The RFADDR register will indicate the current refresh address when read, and a write to the register will change the next refresh address generated.

Figure 34 presents the PWRCON register and STEPID register. The STEPID register contains stepping identifier that may or may not change any time there is a change to the 80C186EB silicon die. The STEPID is for Intel use and can change at any time.

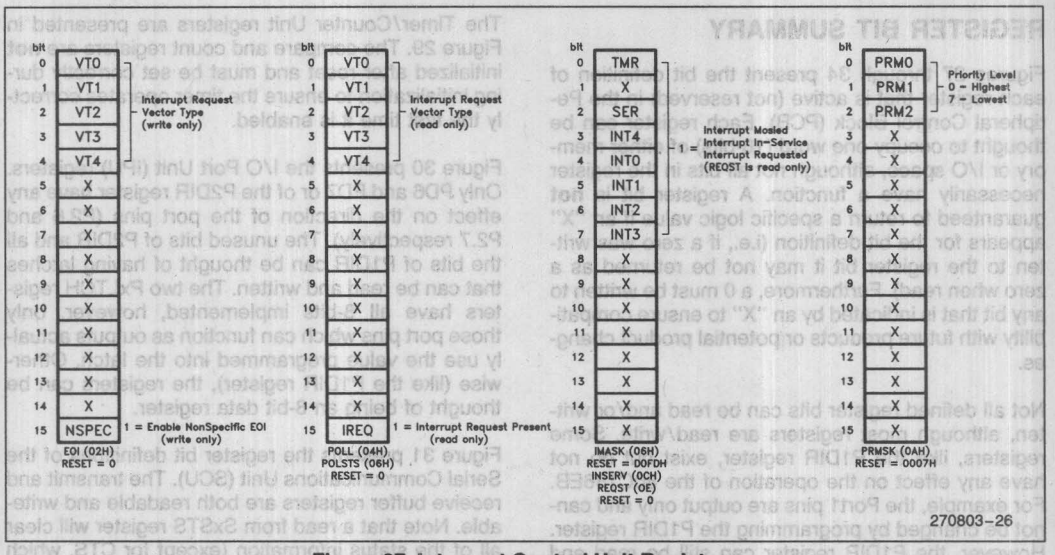


Figure 27. Interrupt Control Unit Registers

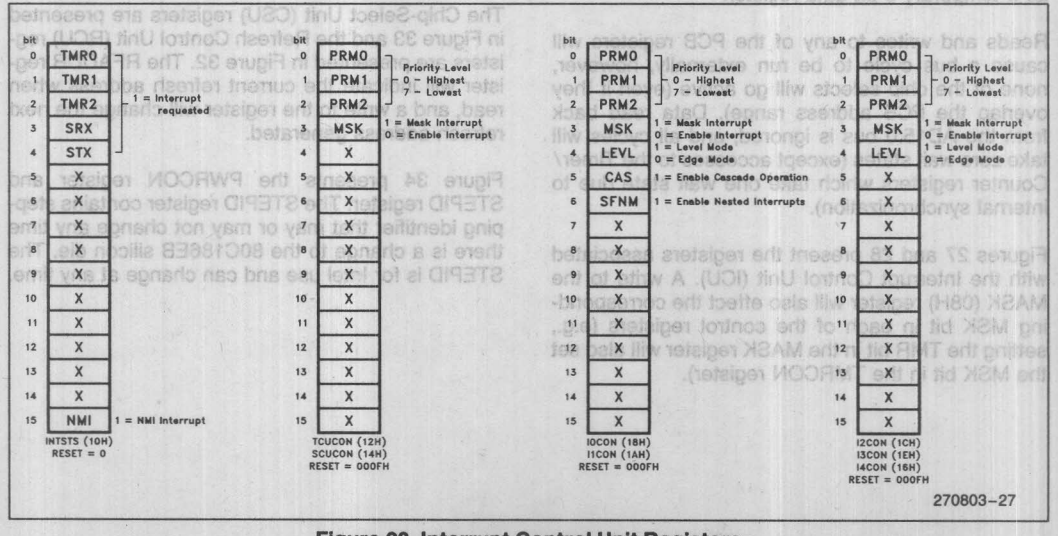


Figure 28. Interrupt Control Unit Registers

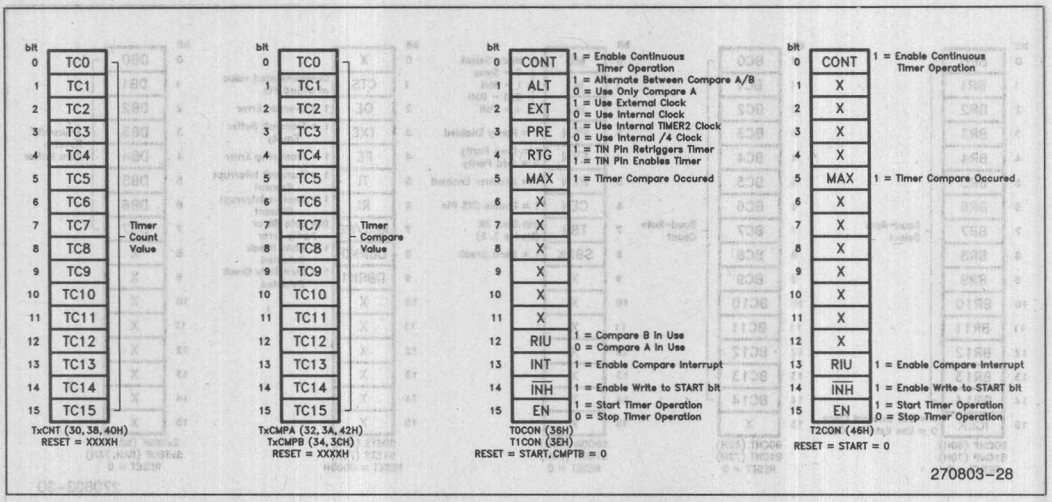


Figure 29. Timer Control Unit Registers

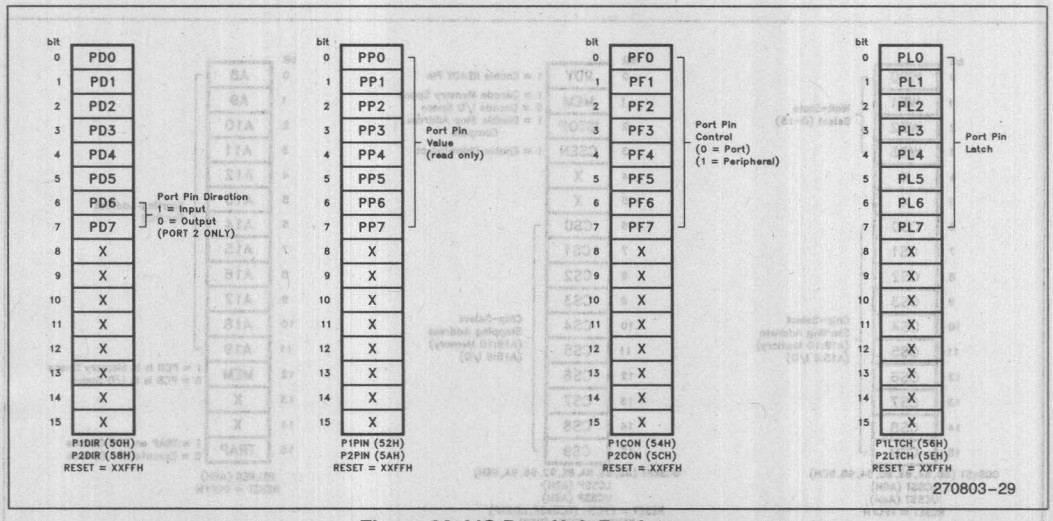


Figure 30. I/O Port Unit Registers

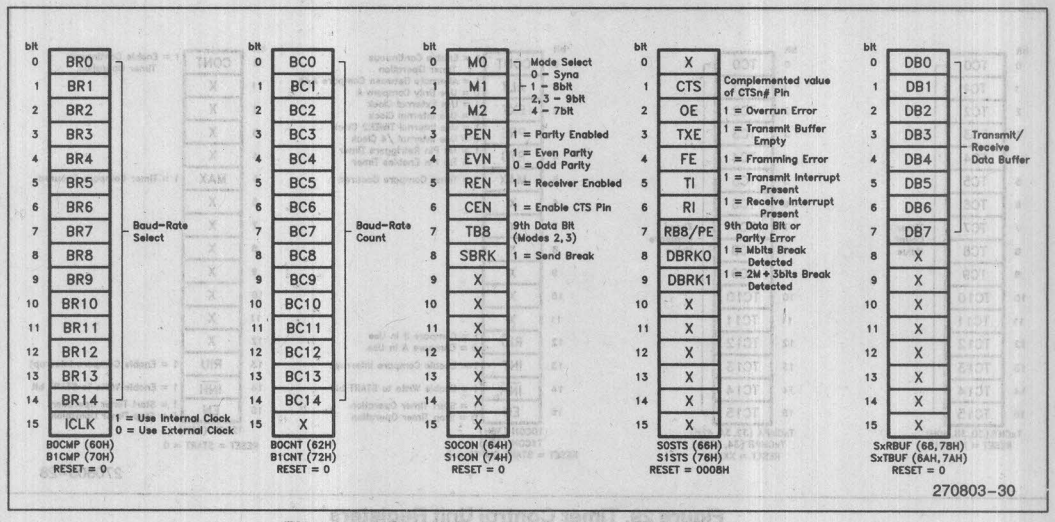


Figure 31. Serial Communications Unit Registers

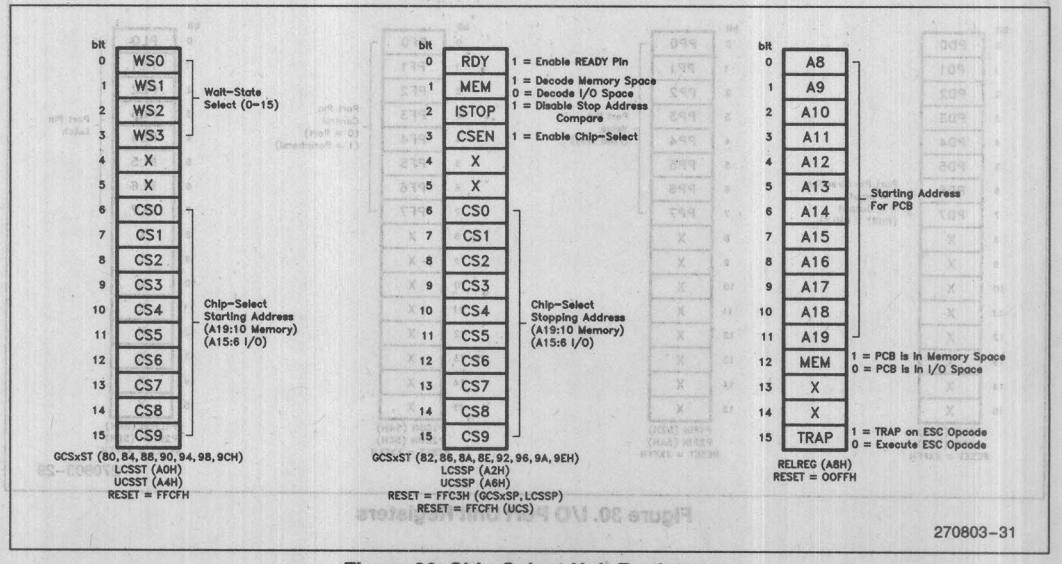


Figure 32. Chip-Select Unit Registers

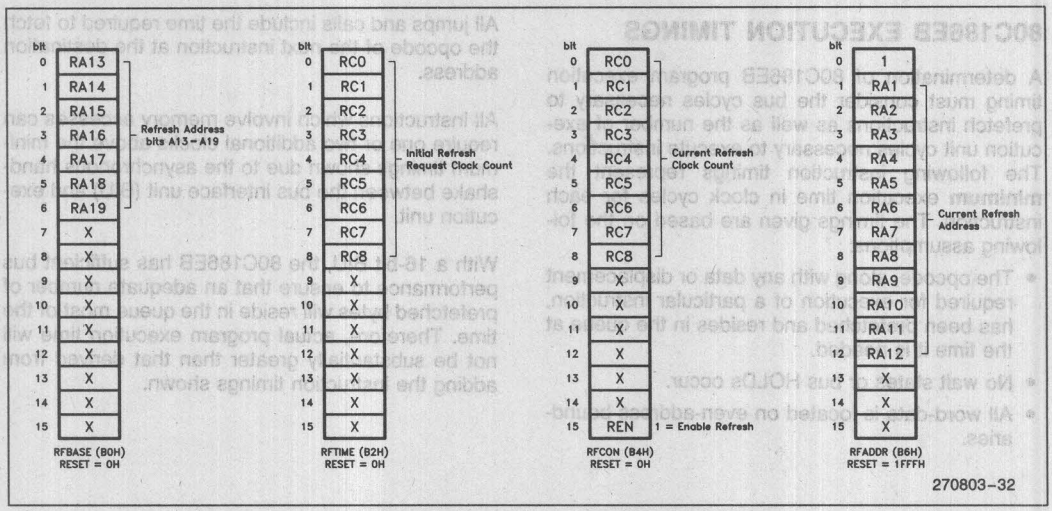


Figure 33. Refresh Control Unit Registers

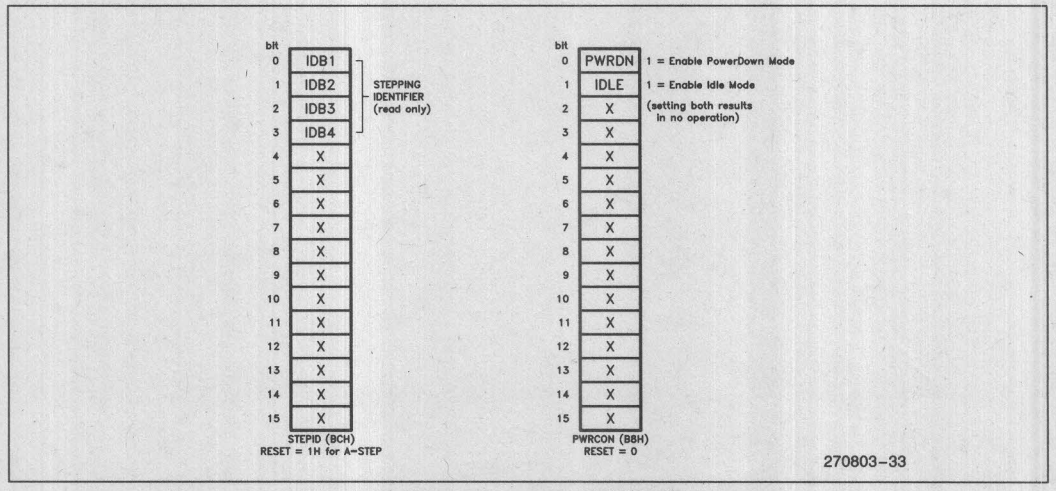


Figure 34. Power Management Unit Registers

80C186EB EXECUTION TIMINGS

A determination of 80C186EB program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the **minimum** execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDs occur.
- All word-data is located on even-address boundaries.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

All instructions which involve memory accesses can require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the bus interface unit (BIU) and execution unit.

With a 16-bit BIU, the 80C186EB has sufficient bus performance to ensure that an adequate number of prefetched bytes will reside in the queue most of the time. Therefore, actual program execution time will not be substantially greater than that derived from adding the instruction timings shown.

INSTRUCTION SET SUMMARY

Function	Format				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1000100w	mod reg r/m			2/12	
Register/memory to register	1000101w	mod reg r/m			2/9	
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1	12–13	8/16-bit
Immediate to register	1011w reg	data	data if w=1		3–4	8/16-bit
Memory to accumulator	1010000w	addr-low	addr-high		8	
Accumulator to memory	1010001w	addr-low	addr-high		9	
Register/memory to segment register	10001110	mod 0 reg r/m			2/9	
Segment register to register/memory	10001100	mod 0 reg r/m			2/11	
PUSH = Push:						
Memory	11111111	mod 1 1 0 r/m			16	
Register	01010 reg				10	
Segment register	000 reg 1 1 0				9	
Immediate	011010s0	data	data if s=0		10	
PUSHA = Push All	01100000				36	
POP = Pop:						
Memory	10001111	mod 0 0 0 r/m			20	
Register	01011 reg				10	
Segment register	000 reg 1 1 1	(reg≠01)			8	
POPA = Pop All	01100001				51	
XCHG = Exchange:						
Register/memory with register	1000011w	mod reg r/m			4/17	
Register with accumulator	10010 reg				3	
IN = Input from:						
Fixed port	1110010w	port			10	
Variable port	1110110w				8	
OUT = Output to:						
Fixed port	1110011w	port			9	
Variable port	1110111w				7	
XLAT = Translate byte to AL	11010111				11	
LEA = Load EA to register	10001101	mod reg r/m			6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)		18	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)		18	
LAHF = Load AH with flags	10011111				2	
SAHF = Store AH into flags	10011110				3	
PUSHF = Push flags	10011100				9	
POPF = Pop flags	10011101				8	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

Immediate to accumulator	0000010w	data	data if w=1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	000100dw	mod reg r/m			3/10	
Immediate to register/memory	100000sw	mod 010 r/m	data	data if sw=01	4/16	
Immediate to accumulator	0001010w	data	data if w=1		3/4	8/16-bit
INC = Increment:						
Register/memory	1111111w	mod 000 r/m			3/15	
Register	01000 reg				3	
SUB = Subtract:						
Reg/memory and register to either	001010dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 101 r/m	data	data if sw=01	4/16	
Immediate from accumulator	0010110w	data	data if w=1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	000110dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 011 r/m	data	data if sw=01	4/16	
Immediate from accumulator	0001110w	data	data if w=1		3/4	8/16-bit
DEC = Decrement						
Register/memory	1111111w	mod 001 r/m			3/15	
Register	01001 reg				3	
CMP = Compare:						
Register/memory with register	0011101w	mod reg r/m			3/10	
Register with register/memory	0011100w	mod reg r/m			3/10	
Immediate with register/memory	100000sw	mod 111 r/m	data	data if sw=01	3/10	
Immediate with accumulator	0011110w	data	data if w=1		3/4	8/16-bit
NEG = Change sign register/memory	1111011w	mod 011 r/m			3/10	
AAA = ASCII adjust for add	00110111				8	
DAA = Decimal adjust for add	00100111				4	
AAS = ASCII adjust for subtract	00111111				7	
DAS = Decimal adjust for subtract	00101111				4	
MUL = Multiply (unsigned):	1111011w	mod 100 r/m				
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
ARITHMETIC (Continued)			
IMUL = Integer multiply (signed):	1111011w | mod101 r/m		
Register-Byte		25–28	
Register-Word		34–37	
Memory-Byte		31–34	
Memory-Word		40–43	
IMUL = Integer Immediate multiply (signed)	011010s1 | mod reg r/m | data | data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1111011w | mod110 r/m		
Register-Byte		29	
Register-Word		38	
Memory-Byte		35	
Memory-Word		44	
IDIV = Integer divide (signed):	1111011w | mod111 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67	
AAM = ASCII adjust for multiply	11010100 | 00001010	19	
AAD = ASCII adjust for divide	11010101 | 00001010	15	
CBW = Convert byte to word	10011000	2	
CWD = Convert word to double word	10011001	4	
LOGIC			
Shift/Rotate Instructions:			
Register/Memory by 1	1101000w | mod TTT r/m	2/15	
Register/Memory by CL	1101001w | mod TTT r/m	5+n/17+n	
Register/Memory by Count	1100000w | mod TTT r/m | count	5+n/17+n	
	TTT Instruction 000 ROL 001 ROR 010 RCL 011 RCR 100 SHL/SAL 101 SHR 111 SAR		
AND = **And:**			
Reg/memory and register to either	001000dw | mod reg r/m	3/10	
Immediate to register/memory	1000000w | mod100 r/m | data | data if w=1	4/16	
Immediate to accumulator	0010010w | data | data if w=1	3/4	8/16-bit
TEST = **And function to flags, no result:**			
Register/memory and register	1000010w | mod reg r/m	3/10	
Immediate data and register/memory	1111011w | mod000 r/m | data | data if w=1	4/10	
Immediate data and accumulator	1010100w | data | data if w=1	3/4	8/16-bit
OR = **Or:**			
Reg/memory and register to either	000010dw | mod reg r/m	3/10	
Immediate to register/memory	1000000w | mod001 r/m | data | data if w=1	4/16	
Immediate to accumulator	0000110w | data | data if w=1	3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
LOGIC (Continued)			
XOR = Exclusive or:			
Reg/memory and register to either	001100dw | mod reg r/m	3/10	
Immediate to register/memory	1000000w | mod 110 r/m | data | data if w=1	4/16	
Immediate to accumulator	0011010w | data | data if w=1	3/4	8/16-bit
NOT = Invert register/memory	1111011w | mod 010 r/m	3/10	
STRING MANIPULATION			
MOVS = Move byte/word	1010010w	14	
CMPS = Compare byte/word	1010011w	22	
SCAS = Scan byte/word	1010111w	15	
LODS = Load byte/wd to AL/AX	1010110w	12	
STOS = Store byte/wd from AL/AX	1010101w	10	
INS = Input byte/wd from DX port	0110110w	14	
OUTS = Output byte/wd to DX port	0110111w	14	
Repeated by count in CX (REP/REPE/REPZ/REPNE/REPNZ)			
MOVS = Move string	11110010 | 1010010w	8+8n	
CMPS = Compare string	1111001z | 1010011w	5+22n	
SCAS = Scan string	1111001z | 1010111w	5+15n	
LODS = Load string	11110010 | 1010110w	6+11n	
STOS = Store string	11110010 | 1010101w	6+9n	
INS = Input string	11110010 | 0110110w	8+8n	
OUTS = Output string	11110010 | 0110111w	8+8n	
CONTROL TRANSFER			
CALL = Call:			
Direct within segment	11101000 | disp-low | disp-high	15	
Register/memory indirect within segment	11111111 | mod 010 r/m	13/19	
Direct intersegment	10011010 | segment offset | segment selector	23	
Indirect intersegment	11111111 | mod 011 r/m (mod ≠ 11)	38	
JMP = Unconditional jump:			
Short/long	11101011 | disp-low	14	
Direct within segment	11101001 | disp-low | disp-high	14	
Register/memory indirect within segment	11111111 | mod 100 r/m	11/17	
Direct intersegment	11101010 | segment offset | segment selector	14	
Indirect intersegment	11111111 | mod 101 r/m (mod ≠ 11)	26	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
RET = **Return from CALL:**						
Within segment	11000011				16	
Within seg adding immed to SP	11000010	data-low	data-high		18	
Intersegment	11001011				22	
Intersegment adding immediate to SP	11001010	data-low	data-high		25	
JE/JZ = Jump on equal/zero	01110100	disp			4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100	disp			4/13	
JLE/JNG = Jump on less or equal/not greater	01111110	disp			4/13	
JB/JNAE = Jump on below/not above or equal	01110010	disp			4/13	
JBE/JNA = Jump on below or equal/not above	01110110	disp			4/13	
JP/JPE = Jump on parity/parity even	01111010	disp			4/13	
JO = Jump on overflow	01110 000	disp			4/13	
JS = Jump on sign	01111000	disp			4/13	
JNE/JNZ = Jump on not equal/not zero	01110101	disp			4/13	
JNL/JGE = Jump on not less/greater or equal	01111101	disp			4/13	
JNLE/JG = Jump on not less or equal/greater	01111111	disp			4/13	
JNB/JAE = Jump on not below/above or equal	01110011	disp			4/13	
JNBE/JA = Jump on not below or equal/above	01110111	disp			4/13	
JNP/JPO = Jump on not par/par odd	01111011	disp			4/13	
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					15	
L = 1					25	
L > 1					22+16(n−1)	
LEAVE = Leave Procedure	11001001				8	
INT = **Interrupt:**						
Type specified	11001101	type			47	
Type 3	11001100				45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	11001110				48/4	
IRET = Interrupt return	11001111				28	
BOUND = Detect value out of range	01100010	mod reg r/m			33–35	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
PROCESSOR CONTROL			
CLC = Clear carry	11111000	2	
CMC = Complement carry	11110101	2	
STC = Set carry	11111001	2	
CLD = Clear direction	11111100	2	
STD = Set direction	11111101	2	
CLI = Clear interrupt	11111010	2	
STI = Set interrupt	11111011	2	
HLT = Halt	11110100	2	
WAIT = Wait	10011011	6	if $\overline{TEST}$ = 0
LOCK = Bus lock prefix	11110000	2	
NOP = No Operation	10010000	3	
	(TTT LLL are opcode to processor extension)		

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

ERRATA

The 80C186EB has the following known errata that apply to any device with a stepping ID (STEPID) of 0001H.

1. A19/$\overline{ONCE}$ is not latched by the rising edge of $\overline{RESIN}$. A19/$\overline{ONCE}$ must remain active (LOW) at all times to remain in the ONCE™ Mode. Removing A19/$\overline{ONCE}$ after $\overline{RESIN}$ is high will return all output pins to a driving state, however, the 80C186EB will remain in a reset state.
2. During interrupt acknowledge (INTA) bus cycles, the bus controller will ignore the state of the READY pin if the previous bus cycle ignored the state of the READY pin. This errata can only occur if the Chip-Select Unit is being used. All active chip-selects must be programmed to use READY (RDY bit must be programmed to a 1) if wait-states are required for INTA bus cycles.
3. CLKOUT will transition off the **rising** edge of CLKIN rather than the falling edge of CLKIN. This does not affect any bus timings other than T_{CD}.
4. $\overline{RESIN}$ has a hysterisis of only 130 mV. It is recommended that $\overline{RESIN}$ be driven by a Schmitt triggered device to avoid processor lockup during reset using an RC circuit.

REVISION HISTORY

The following changes have been made between the -001 version and this (-002) version of the 80C186EB data sheet.

1. Figure 1 was updated to correct for incorrect pin names (TXD1 and $\overline{TEST}$/BUSY), and to rename the Powerdown Control Unit to the Power Management Unit.
2. Figure 6 was corrected to indicate that the STEP ID register is located at 0BCH (not 0BAH), and to rename the INTx control registers.
3. Page 12, Power Control Unit was changed to Power Management Unit.
4. Figure 7 was corrected to indicate that the AD15:0 are P(X) rather than P(Z).
5. Table 3 was updated. The following list of pins either had changes to their TYPE field or their DESCRIPTION field.
   OSCOUT, PDTMR, AD15:0, A19:16, $\overline{S2:0}$, $\overline{DEN}$, $\overline{LOCK}$, HLDA, P1.0–P1.7, TxOUT, INT4, SINT1.
6. Figures 7 and 8 were updated to change pin name P2.3/SINT to P2.3/SINT1.
7. PDTMR pin capacitance chart was added to page 27.
8. TCD specification was changed to 20, 23, 27 ns for the -16, -13, and -8 devices respectively.
9. Serial port timings on page 32 were updated.
10. Figures 17 and 18 were updated to correctly identify the names of signals affected by $\overline{RESIN}$.
11. Correction of the text describing Figures 30 and 31.
12. Changes I4CON register location described in Figure 28.
13. The description of P1CON and P2CON in Figure 30 was changed to indicate that a 0 selects the Port function, while a 1 selects the Peripheral function.
14. Changed Figure 34 description to Power Management Unit.
15. Added $\overline{RESIN}$ hysterisis anamoly to errata descriptions.

80C187
80-BIT MATH COPROCESSOR

- **High Performance 80-Bit Internal Architecture**
- **Implements ANSI/IEEE Standard 754-1985 for Binary Floating-Point Arithmetic**
- **Upward Object-Code Compatible from 8087**
- **Fully Compatible with 387™DX and 387™SX Math Coprocessors. Implements all 387 Architectural Enhancements over 8087**
- **Directly Interfaces with 80C186 CPU**
- **80C186/80C187 Provide a Software/Binary Compatible Upgrade from 80186/82188/8087 Systems**
- **Expands 80C186's Data Types to Include 32-, 64-, 80-Bit Floating-Point, 32-, 64-Bit Integers and 18-Digit BCD Operands**
- **Directly Extends 80C186's Instruction Set to Trigonometric, Logarithmic, Exponential, and Arithmetic Instructions for All Data Types**
- **Full-Range Transcendental Operations for SINE, COSINE, TANGENT, ARCTANGENT, and LOGARITHM**
- **Built-In Exception Handling**
- **Eight 80-Bit Numeric Registers, Usable as Individually Addressable General Registers or as a Register Stack**
- **Available in 40-Pin CERDIP and 44-Pin PLCC Package**

(See Packaging Outlines and Dimensions, Order #231369)

The Intel 80C187 is a high-performance math coprocessor that extends the architecture of the 80C186 with floating-point, extended integer, and BCD data types. A computing system that includes the 80C187 fully conforms to the IEEE Floating-Point Standard. The 80C187 adds over seventy mnemonics to the instruction set of the 80C186, including support for arithmetic, logarithmic, exponential, and trigonometric mathematical operations. The 80C187 is implemented with 1.5 micron, high-speed CHMOS III technology and packaged in both a 40-pin CERDIP and a 44-pin PLCC package. The 80C187 is upward object-code compatible from the 8087 math coprocessor and will execute code written for the 80387DX and 80387SX math coprocessors.

August 1990
Order Number: 270640-004

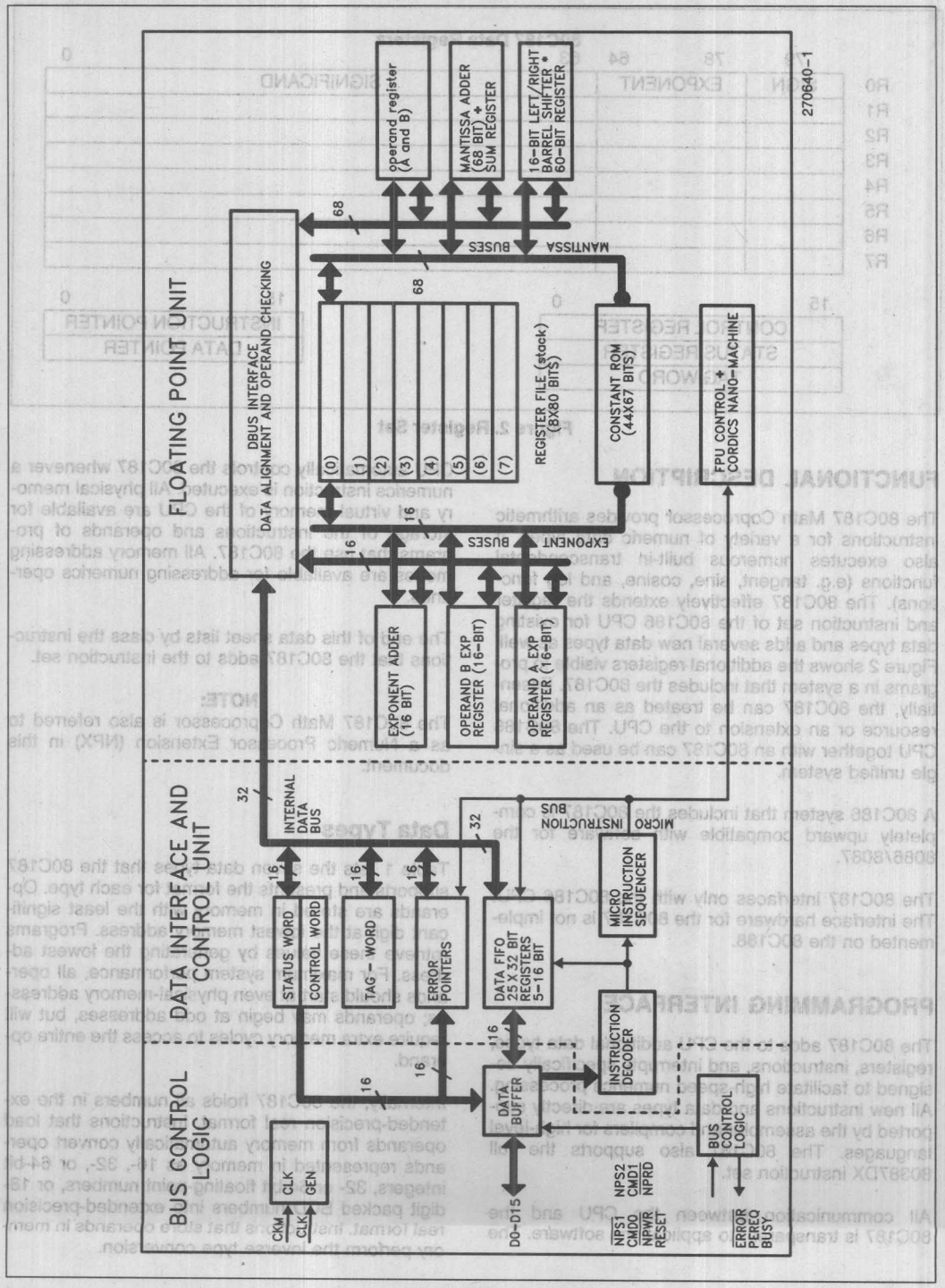


Figure 1. 80C187 Block Diagram

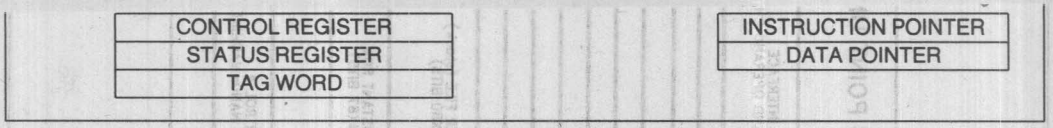


Figure 2. Register Set

FUNCTIONAL DESCRIPTION

The 80C187 Math Coprocessor provides arithmetic instructions for a variety of numeric data types. It also executes numerous built-in transcendental functions (e.g. tangent, sine, cosine, and log functions). The 80C187 effectively extends the register and instruction set of the 80C186 CPU for existing data types and adds several new data types as well. Figure 2 shows the additional registers visible to programs in a system that includes the 80C187. Essentially, the 80C187 can be treated as an additional resource or an extension to the CPU. The 80C186 CPU together with an 80C187 can be used as a single unified system.

A 80C186 system that includes the 80C187 is completely upward compatible with software for the 8086/8087.

The 80C187 interfaces only with the 80C186 CPU. The interface hardware for the 80C187 is not implemented on the 80C188.

PROGRAMMING INTERFACE

The 80C187 adds to the CPU additional data types, registers, instructions, and interrupts specifically designed to facilitate high-speed numerics processing. All new instructions and data types are directly supported by the assembler and compilers for high-level languages. The 80C187 also supports the full 80387DX instruction set.

All communication between the CPU and the 80C187 is transparent to applications software. The CPU automatically controls the 80C187 whenever a numerics instruction is executed. All physical memory and virtual memory of the CPU are available for storage of the instructions and operands of programs that use the 80C187. All memory addressing modes are available for addressing numerics operands.

The end of this data sheet lists by class the instructions that the 80C187 adds to the instruction set.

NOTE:
The 80C187 Math Coprocessor is also referred to as a Numeric Processor Extension (NPX) in this document.

Data Types

Table 1 lists the seven data types that the 80C187 supports and presents the format for each type. Operands are stored in memory with the least significant digit at the lowest memory address. Programs retrieve these values by generating the lowest address. For maximum system performance, all operands should start at even physical-memory addresses; operands may begin at odd addresses, but will require extra memory cycles to access the entire operand.

Internally, the 80C187 holds all numbers in the extended-precision real format. Instructions that load operands from memory automatically convert operands represented in memory as 16-, 32-, or 64-bit integers, 32- or 64-bit floating-point numbers, or 18-digit packed BCD numbers into extended-precision real format. Instructions that store operands in memory perform the inverse type conversion.

Numeric Operands

A typical NPX instruction accepts one or two operands and produces one (or sometimes two) results. In two-operand instructions, one operand is the contents of an NPX register, while the other may be a memory location. The operands of some instructions are predefined; for example, FSQRT always takes the square root of the number in the top stack element (refer to the section on Data Registers).

Register Set

Figure 2 shows the 80C187 register set. When an 80C187 is present in a system, programmers may use these registers in addition to the registers normally available on the CPU.

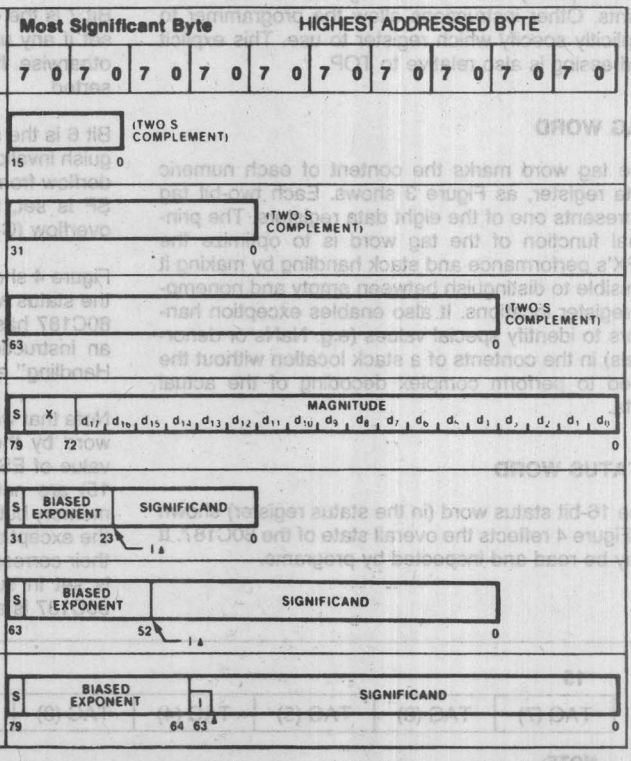
DATA REGISTERS

80C187 computations use the extended-precision real data type.

1

Table 1. Data Type Representation in Memory

Data Formats	Range	Precision	Most Significant Byte ... HIGHEST ADDRESSED BYTE
Word Integer	$\pm 10^4$	16 Bits	(TWO S COMPLEMENT)
Short Integer	$\pm 10^9$	32 Bits	(TWO S COMPLEMENT)
Long Integer	$\pm 10^{18}$	64 Bits	(TWO S COMPLEMENT)
Packed BCD	$\pm 10^{18}$	18 Digits	S, X, MAGNITUDE
Single Precision	$\pm 10^{\pm 38}$	24 Bits	S, BIASED EXPONENT, SIGNIFICAND
Double Precision	$\pm 10^{\pm 308}$	53 Bits	S, BIASED EXPONENT, SIGNIFICAND
Extended Precision	$\pm 10^{\pm 4932}$	64 Bits	S, BIASED EXPONENT, I, SIGNIFICAND



270640-2

NOTES:
1. S = Sign bit (0 = Positive, 1 = Negative)
2. d_n = Decimal digit (two per byte)
3. X = Bits have no significance; 80C187 ignores when loading, zeros when storing
4. ▲ = Position of implicit binary point
5. I = Integer bit of significand; stored in temporary real, implicit in single and double precision
6. Exponent Bias (normalized values):
   Single: 127 (7FH)
   Double: 1023 (3FFH)
   Extended Real: 16383 (3FFFH)
7. Packed BCD: $(-1)^S (D_{17} \ldots D_0)$
8. Real: $(-1)^S (2^{E-BIAS}) (F_0, F_1 \ldots)$

The 80C187 register set can be accessed either as a stack, with instructions operating on the top one or two stack elements, or as individually addressable registers. The TOP field in the status word identifies the current top-of-stack register. A "push" operation decrements TOP by one and loads a value into the new top register. A "pop" operation stores the value from the current top register and then increments TOP by one. The 80C187 register stack grows "down" toward lower-addressed registers.

Instructions may address the data registers either implicitly or explicitly. Many instructions operate on the register at the TOP of the stack. These instructions implicitly address the register at which TOP points. Other instructions allow the programmer to explicitly specify which register to use. This explicit addressing is also relative to TOP.

TAG WORD

The tag word marks the content of each numeric data register, as Figure 3 shows. Each two-bit tag represents one of the eight data registers. The principal function of the tag word is to optimize the NPX's performance and stack handling by making it possible to distinguish between empty and nonempty register locations. It also enables exception handlers to identify special values (e.g. NaNs or denormals) in the contents of a stack location without the need to perform complex decoding of the actual data.

STATUS WORD

The 16-bit status word (in the status register) shown in Figure 4 reflects the overall state of the 80C187. It may be read and inspected by programs.

Bit 15, the B-bit (busy bit) is included for 8087 compatibility only. It always has the same value as the ES bit (bit 7 of the status word); it does **not** indicate the status of the BUSY output of 80C187.

Bits 13–11 (TOP) point to the 80C187 register that is the current top-of-stack.

The four numeric condition code bits (C_3–C_0) are similar to the flags in a CPU; instructions that perform arithmetic operations update these bits to reflect the outcome. The effects of these instructions on the condition code are summarized in Tables 2 through 5.

Bit 7 is the error summary (ES) status bit. This bit is set if any unmasked exception bit is set; it is clear otherwise. If this bit is set, the $\overline{\text{ERROR}}$ signal is asserted.

Bit 6 is the stack flag (SF). This bit is used to distinguish invalid operations due to stack overflow or underflow from other kinds of invalid operations. When SF is set, bit 9 (C_1) distinguishes between stack overflow ($C_1 = 1$) and underflow ($C_1 = 0$).

Figure 4 shows the six exception flags in bits 5–0 of the status word. Bits 5–0 are set to indicate that the 80C187 has detected an exception while executing an instruction. A later section entitled "Exception Handling" explains how they are set and used.

Note that when a new value is loaded into the status word by the FLDENV or FRSTOR instruction, the value of ES (bit 7) and its reflection in the B-bit (bit 15) are not derived from the values loaded from memory but rather are dependent upon the values of the exception flags (bits 5–0) in the status word and their corresponding masks in the control word. If ES is set in such a case, the $\overline{\text{ERROR}}$ output of the 80C187 is activated immediately.

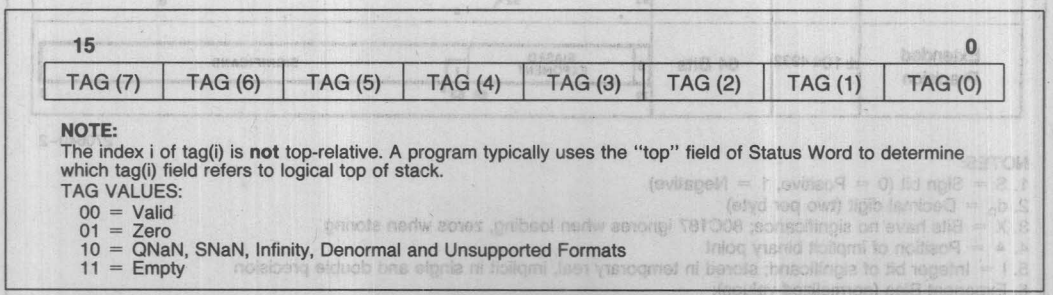


Figure 3. Tag Word

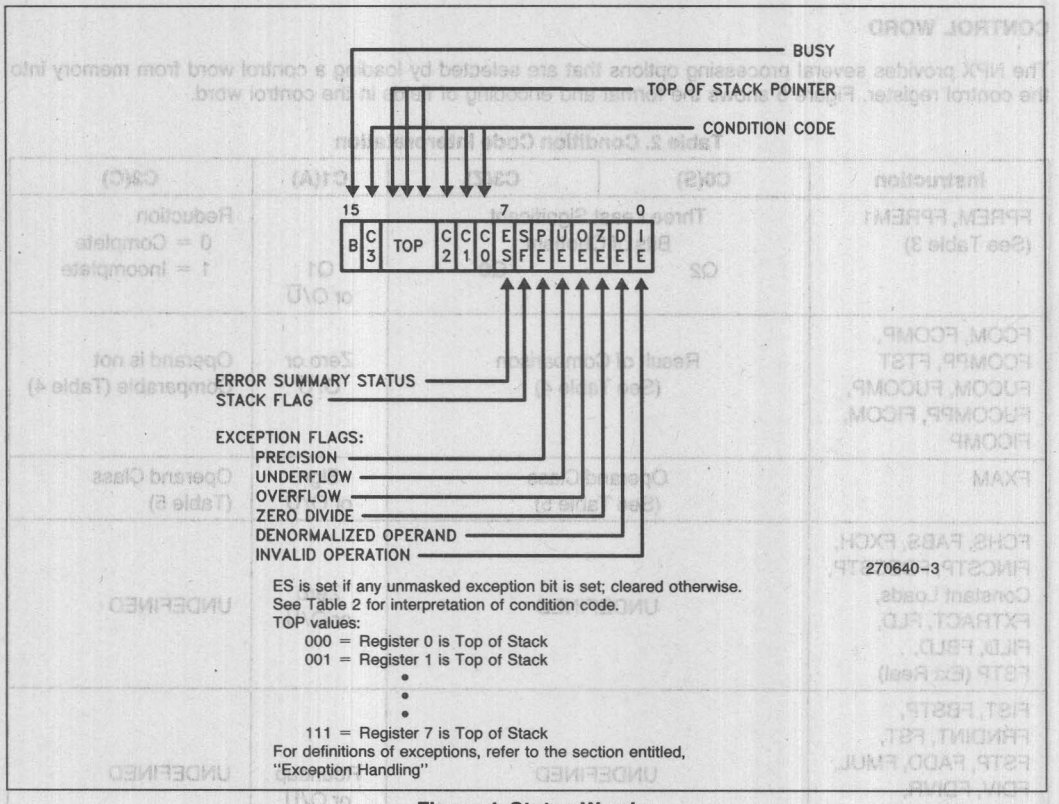


Figure 4. Status Word

CONTROL WORD

The NPX provides several processing options that are selected by loading a control word from memory into the control register. Figure 5 shows the format and encoding of fields in the control word.

Table 2. Condition Code Interpretation

Instruction	C0(S)	C3(Z)	C1(A)	C2(C)
FPREM, FPREM1 (See Table 3)	Three Least Significant Bits of Quotient Q2 Q0		Q1 or O/$\overline{U}$	Reduction 0 = Complete 1 = Incomplete
FCOM, FCOMP, FCOMPP, FTST FUCOM, FUCOMP, FUCOMPP, FICOM, FICOMP	Result of Comparison (See Table 4)		Zero or O/$\overline{U}$	Operand is not Comparable (Table 4)
FXAM	Operand Class (See Table 5)		Sign or O/$\overline{U}$	Operand Class (Table 5)
FCHS, FABS, FXCH, FINCSTP, FDECSTP, Constant Loads, FXTRACT, FLD, FILD, FBLD, FSTP (Ext Real)	UNDEFINED		Zero or O/$\overline{U}$	UNDEFINED
FIST, FBSTP, FRNDINT, FST, FSTP, FADD, FMUL, FDIV, FDIVR, FSUB, FSUBR, FSCALE, FSQRT, FPATAN, F2XM1, FYL2X, FYL2XP1	UNDEFINED		Roundup or O/$\overline{U}$	UNDEFINED
FPTAN, FSIN, FCOS, FSINCOS	UNDEFINED		Roundup or O/$\overline{U}$, Undefined if C2 = 1	Reduction 0 = Complete 1 = Incomplete
FLDENV, FRSTOR	Each Bit Loaded from Memory			
FLDCW, FSTENV, FSTCW, FSTSW, FCLEX, FINIT, FSAVE	UNDEFINED			

O/$\overline{U}$ When both IE and SF bits of status word are set, indicating a stack exception, this bit distinguishes between stack overflow (C1 = 1) and underflow (C1 = 0).

Reduction If FPREM or FPREM1 produces a remainder that is less than the modulus, reduction is complete. When reduction is incomplete the value at the top of the stack is a partial remainder, which can be used as input to further reduction. For FPTAN, FSIN, FCOS, and FSINCOS, the reduction bit is set if the operand at the top of the stack is too large. In this case the original operand remains at the top of the stack.

Roundup When the PE bit of the status word is set, this bit indicates whether one was added to the least significant bit of the result during the last rounding.

UNDEFINED Do not rely on finding any specific value in these bits.

The low-order byte of this control word configures exception masking. Bits 5–0 of the control word contain individual masks for each of the six exceptions that the 80C187 recognizes.

The high-order byte of the control word configures the 80C187 operating mode, including precision, rounding, and infinity control.

- The "infinity control bit" (bit 12) is not meaningful to the 80C187, and programs must ignore its value. To maintain compatibility with the 8087, this bit can be programmed; however, regardless of its value, the 80C187 always treats infinity in the affine sense ($-\infty < +\infty$). This bit is initialized to zero both after a hardware reset and after the FINIT instruction.
- The rounding control (RC) bits (bits 11–10) provide for directed rounding and true chop, as well as the unbiased round to nearest even mode specified in the IEEE standard. Rounding control affects only those instructions that perform rounding at the end of the operation (and thus can generate a precision exception); namely, FST, FSTP, FIST, all arithmetic instructions (except FPREM, FPREM1, FXTRACT, FABS, and FCHS), and all transcendental instructions.
- The precision control (PC) bits (bits 9–8) can be used to set the 80C187 internal operating precision of the significand at less than the default of 64 bits (extended precision). This can be useful in providing compatibility with early generation arithmetic processors of smaller precision. PC affects only the instructions ADD, SUB, DIV, MUL, and SQRT. For all other instructions, either the precision is determined by the opcode or extended precision is used.

1

Table 3. Condition Code Interpretation after FPREM and FPREM1 Instructions

Condition Code				Interpretation after FPREM and FPREM1
C2	C3	C1	C0	
1	X	X	X	Incomplete Reduction: Further Iteration Required for Complete Reduction
	Q1	Q0	Q2	Q MOD 8
0	0	0	0	0
	0	1	0	1
	1	0	0	2
	1	1	0	3
	0	0	1	4
	0	1	1	5
	1	0	1	6
	1	1	1	7

Complete Reduction: C0, C3, C1 Contain Three Least Significant Bits of Quotient

Table 4. Condition Code Resulting from Comparison

Order	C3	C2	C0
TOP > Operand	0	0	0
TOP < Operand	0	0	1
TOP = Operand	1	0	0
Unordered	1	1	1

Table 5. Condition Code Defining Operand Class

C3	C2	C1	C0	Value at TOP
0	0	0	0	+ Unsupported
0	0	0	1	+ NaN
0	0	1	0	− Unsupported
0	0	1	1	− NaN
0	1	0	0	+ Normal
0	1	0	1	+ Infinity
0	1	1	0	− Normal
0	1	1	1	− Infinity
1	0	0	0	+ 0
1	0	0	1	+ Empty
1	0	1	0	− 0
1	0	1	1	− Empty
1	1	0	0	+ Denormal
1	1	1	1	− Denormal

INSTRUCTION AND DATA POINTERS

Because the NPX operates in parallel with the CPU, any exceptions detected by the NPX may be reported after the CPU has executed the ESC instruction which caused it. To allow identification of the failing numerics instruction, the 80C187 contains registers that aid in diagnosis. These registers supply the opcode of the failing numerics instruction, the address of the instruction, and the address of its numerics memory operand (if appropriate).

The instruction and data pointers are provided for user-written exception handlers. Whenever the 80C187 executes a new ESC instruction, it saves the address of the instruction (including any prefixes that may be present), the address of the operand (if present), and the opcode.

The instruction and data pointers appear in the format shown by Figure 6. The ESC instruction FLDENV, FSTENV, FSAVE and FRSTOR are used to transfer these values between the registers and memory. Note that the value of the data pointer is *undefined* if the prior ESC instruction did not have a memory operand.

Interrupt Description

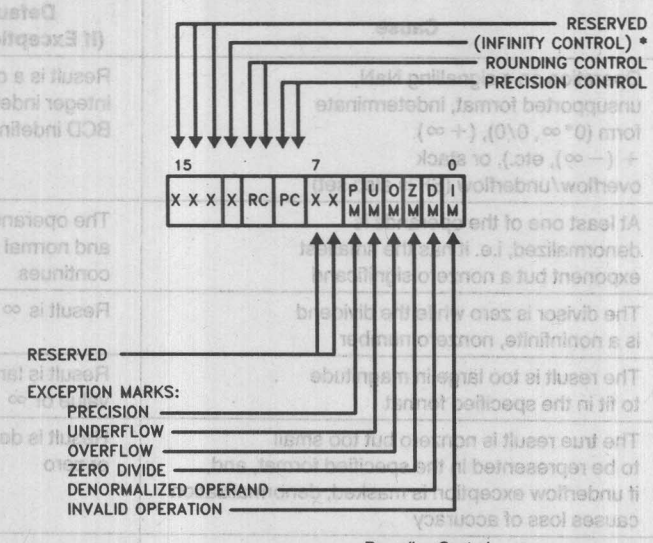
CPU interrupt 16 is used to report exceptional conditions while executing numeric programs. Interrupt 16 indicates that the previous numerics instruction caused an unmasked exception. The address of the faulty instruction and the address of its operand are stored in the instruction pointer and data pointer registers. Only ESC instructions can cause this interrupt. The CPU return address pushed onto the stack of the exception handler points to an ESC instruction (including prefixes). This instruction can be restarted after clearing the exception condition in the NPX. FNINIT, FNCLEX, FNSTSW, FNSTENV, and FNSAVE cannot cause this interrupt.

Exception Handling

The 80C187 detects six different exception conditions that can occur during instruction execution. Table 6 lists the exception conditions in order of precedence, showing for each the cause and the default action taken by the 80C187 if the exception is masked by its corresponding mask bit in the control word.

Any exception that is not masked by the control word sets the corresponding exception flag of the status word, sets the ES bit of the status word, and asserts the $\overline{\text{ERROR}}$ signal. When the CPU attempts to execute another ESC instruction, interrupt 16 occurs. The exception condition must be resolved via an interrupt service routine. The return address pushed onto the CPU stack upon entry to the service routine does not necessarily point to the failing instruction nor to the following instruction. The 80C187 saves the address of the floating-point instruction that caused the exception and the address of any memory operand required by that instruction.

If error trapping is required at the end of a series of numerics instructions (specifically, when the last ESC instruction modifies memory data and that data is used in subsequent nonnumerics instructions), it is necessary to insert the FNOP instruction to force the 80C187 to check its $\overline{\text{ERROR}}$ input.



Precision Control
00— 24 Bits (Single Precision)
01— (Reserved)
10— 53 Bits (Double Precision)
11— 64 Bits (Extended Precision)

Rounding Control
00— Round to Nearest or Even
01— Round Down (toward $-\infty$)
10— Round Up (toward $+\infty$)
11— Chop (Truncate toward Zero)

*The "infinity control" bit is not meaningful to the 80C187. To maintain compatibility with the 8087, this bit can be programmed; however, regardless of its value, the 80C187 treats infinity in the affine sense ($-\infty < +\infty$).

Figure 5. Control Word

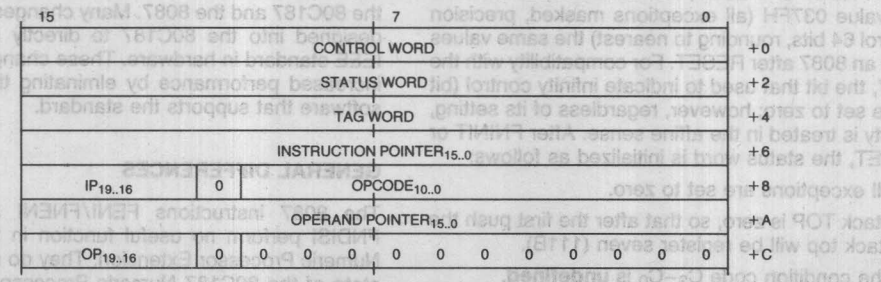


Figure 6. Instruction and Data Pointer Image in Memory

Zero Divisor	The divisor is zero while the dividend is a noninfinite, nonzero number	Result is ∞
Overflow	The result is too large in magnitude to fit in the specified format	Result is largest finite value or ∞
Underflow	The true result is nonzero but too small to be represented in the specified format, and, if underflow exception is masked, denormalization causes loss of accuracy	Result is denormalized or zero
Inexact Result (Precision)	The true result is not exactly representable in the specified format (e.g. 1/3); the result is rounded according to the rounding mode	Normal processing continues

Initialization

After FNINIT or RESET, the control word contains the value 037FH (all exceptions masked, precision control 64 bits, rounding to nearest) the same values as in an 8087 after RESET. For compatibility with the 8087, the bit that used to indicate infinity control (bit 12) is set to zero; however, regardless of its setting, infinity is treated in the affine sense. After FNINIT or RESET, the status word is initialized as follows:

- All exceptions are set to zero.
- Stack TOP is zero, so that after the first push the stack top will be register seven (111B).
- The condition code C_3–C_0 is **undefined**.
- The B-bit is zero.

The tag word contains FFFFH (all stack locations are empty).

80C186/80C187 initialization software should execute an FNINIT instruction (i.e. an FINIT without a preceding WAIT) after RESET. The FNINIT is not strictly required for 80C187 software, but Intel recommends its use to help ensure upward compatibility with other processors.

8087 Compatibility

This section summarizes the differences between the 80C187 and the 8087. Many changes have been designed into the 80C187 to directly support the IEEE standard in hardware. These changes result in increased performance by elminating the need for software that supports the standard.

GENERAL DIFFERENCES

The 8087 instructions FENI/FNENI and FDISI/FNDISI perform no useful function in the 80C187 Numeric Processor Extension. They do not alter the state of the 80C187 Numeric Processor Extension. (They are treated similarly to FNOP, except that $\overline{\text{ERROR}}$ is not checked.) While 8086/8087 code containing these instructions can be executed on the 80C186/80C187, it is unlikely that the exception-handling routines containing these instructions will be completely portable to the 80C187 Numeric Processor Extension.

The 80C187 differs from the 8087 with respect to instruction, data, and exception synchronization. Except for the processor control instructions, all of the 80C187 numeric instructions are automatically synchronized by the 80C186 CPU. When necessary, the

80C186 automatically tests the BUSY line from the 80C187 Numeric Processor Extension to ensure that the 80C187 Numeric Processor Extension has completed its previous instruction before executing the next ESC instruction. No explicit WAIT instructions are required to assure this synchronization. For the 8087 used with 8086 and 8088 CPUs, explicit WAITs are required before each numeric instruction to ensure synchronization. Although 8086/8087 programs having explicit WAIT instructions will execute on the 80C186/80C187, these WAIT instructions are unnecessary.

The 80C187 supports only affine closure for infinity arithmetic, not projective closure.

Operands for FSCALE and FPATAN are no longer restricted in range (except for $\pm\infty$); F2XM1 and FPTAN accept a wider range of operands.

Rounding control is in effect for FLD *constant*.

Software cannot change entries of the tag word to values (other than empty) that differ from actual register contents.

After reset, FINIT, and incomplete FPREM, the 80C187 resets to zero the condition code bits C_3–C_0 of the status word.

In conformance with the IEEE standard, the 80C187 does not support the special data formats pseudozero, pseudo-NaN, pseudoinfinity, and unnormal.

The denormal exception has a different purpose on the 80C187. A system that uses the denormal-exception handler solely to normalize the denormal operands, would better mask the denormal exception on the 80C187. The 80C187 automatically normalizes denormal operands when the denormal exception is masked.

EXCEPTIONS

A number of differences exist due to changes in the IEEE standard and to functional improvements to the architecture of the 80C186/80C187:

1. The 80C186/80C187 traps exceptions only on the next ESC instruction; i.e. the 80C186 does not notice unmasked 80C187 exceptions on the 80C186 $\overline{\text{ERROR}}$ input line until a later numerics instruction is executed. Because the 80C186 does not sample $\overline{\text{ERROR}}$ on WAIT and FWAIT instructions, programmers should place an FNOP instruction at the end of a sequence of numerics *instructions to force the 80C186 to sample its* $\overline{\text{ERROR}}$ input.
2. The 80C187 Numeric Processor Extension signals exceptions through a dedicated $\overline{\text{ERROR}}$ line to the CPU. The 80C187 error signal does not pass through an interrupt controller (the 8087 INT signal does). Therefore, any interrupt-controller-oriented instructions in numerics exception handlers for the 8086/8087 should be deleted.
3. Interrupt vector 16 must point to the numerics exception handling routine.
4. The ESC instruction address saved in the 80C187 Numeric Processor Extension includes any leading prefixes before the ESC opcode. The corresponding address saved in the 8087 does not include leading prefixes.
5. When the overflow or underflow exception is masked, the 80C187 differs from the 8087 in rounding when overflow or underflow occurs. The 80C187 produces results that are consistent with the rounding mode.
6. When the underflow exception is masked, the 80C187 sets its underflow flag only if there is also a loss of accuracy during denormalization.
7. Fewer invalid-operation exceptions due to denormal operands, because the instructions FSQRT, FDIV, FPREM, and conversions to BCD or to integer normalize denormal operands before proceeding.
8. The FSQRT, FBSTP, and FPREM instructions may cause underflow, because they support denormal operands.
9. The denormal exception can occur during the transcendental instructions and the FXTRACT instruction.
10. The denormal exception no longer takes precedence over all other exceptions.
11. When the denormal exception is masked, the 80C187 automatically normalizes denormal operands. The 8087 performs unnormal arithmetic, which might produce an unnormal result.
12. When the operand is zero, the FXTRACT instruction reports a zero-divide exception and leaves $-\infty$ in ST(1).
13. The status word has a new bit (SF) that signals when invalid-operation exceptions are due to stack underflow or overflow.
14. FLD *extended precision* no longer reports denormal exceptions, because the instruction is not numeric.
15. FLD *single/double precision* when the operand is denormal converts the number to extended precision and signals the denormalized oper-

and exception. When loading a signalling NaN, FLD *single/double precision* signals an invalid-operand exception.

16. The 80C187 only generates quiet NaNs (as on the 8087); however, the 80C187 distinguishes between quiet NaNs and signalling NaNs. Signalling NaNs trigger exceptions when they are used as operands; quiet NaNs do not (except for FCOM, FIST, and FBSTP which also raise IE for quiet NaNs).
17. When stack overflow occurs during FPTAN and overflow is masked, both ST(0) and ST(1) contain quiet NaNs. The 8087 leaves the original operand in ST(1) intact.
18. When the scaling factor is $\pm\infty$, the FSCALE (ST(0), ST(1) instruction behaves as follows (ST(0) and ST(1) contain the scaled and scaling operands respectively):
    - FSCALE (0, ∞) generates the invalid operation exception.
    - FSCALE (finite, $-\infty$) generates zero with the same sign as the scaled operand.
    - FSCALE (finite, $+\infty$) generates ∞ with the same sign as the scaled operand.

    The 8087 returns zero in the first case and raises the invalid-operation exception in the other cases.
19. The 80C187 returns signed infinity/zero as the unmasked response to massive overflow/underflow. The 8087 supports a limited range for the scaling factor; within this range either massive overflow/underflow do not occur or undefined results are produced.

Table 7. Pin Summary

Pin Name	Function	Active State	Input/ Output
CLK	CLocK		I
CKM	ClocKing Mode		I
RESET	System reset	High	I
PEREQ	Processor Extension REQuest	High	O
BUSY	Busy status	High	O
$\overline{\text{ERROR}}$	Error status	Low	O
D_{15}–D_0	Data pins	High	I/O
$\overline{\text{NPRD}}$	Numeric Processor ReaD	Low	I
$\overline{\text{NPWR}}$	Numeric Processor WRite	Low	I
$\overline{\text{NPS1}}$	NPX select #1	Low	I
NPS2	NPX select #2	High	I
CMD0	CoMmanD 0	High	I
CMD1	CoMmanD 1	High	I
V_{CC}	System power		I
V_{SS}	System ground		I

HARDWARE INTERFACE

In the following description of hardware interface, an overbar above a signal name indicates that the active or asserted state occurs when the signal is at a low voltage. When no overbar is present above the signal name, the signal is asserted when at the high voltage level.

Signal Description

In the following signal descriptions, the 80C187 pins are grouped by function as follows:

1. Execution Control— CLK, CKM, RESET
2. NPX Handshake— PEREQ, BUSY, $\overline{\text{ERROR}}$
3. Bus Interface Pins— D_{15}–D_0, $\overline{\text{NPWR}}$, $\overline{\text{NPRD}}$
4. Chip/Port Select— $\overline{\text{NPS1}}$, NPS2, CMD0, CMD1
5. Power Supplies— V_{CC}, V_{SS}

Table 7 lists every pin by its identifier, gives a brief description of its function, and lists some of its characteristics. Figure 7 shows the locations of pins on the CERDIP package, while Figure 8 shows the locations of pins on the PLCC package. Table 8 helps to locate pin identifiers in Figures 7 and 8.

Clock (CLK)

This input provides the basic timing for internal operation. This pin does not require MOS-level input; it will operate at either TTL or MOS levels up to the maximum allowed frequency. A minimum frequency must be provided to keep the internal logic properly functioning. Depending on the signal on CKM, the signal on CLK can be divided by two to produce the internal clock signal (in which case CLK may be up to 32 MHz in frequency), or can be used directly (in which case CLK may be up to 12.5 MHz).

Clocking Mode (CKM)

This pin is a strapping option. When it is strapped to V_{CC} (HIGH), the CLK input is used directly; when strapped to V_{SS} (LOW), the CLK input is divided by two to produce the internal clock signal. During the RESET sequence, this input must be stable at least four internal clock cycles (i.e. CLK clocks when CKM is HIGH; 2 × CLK clocks when CKM is LOW) before RESET goes LOW.

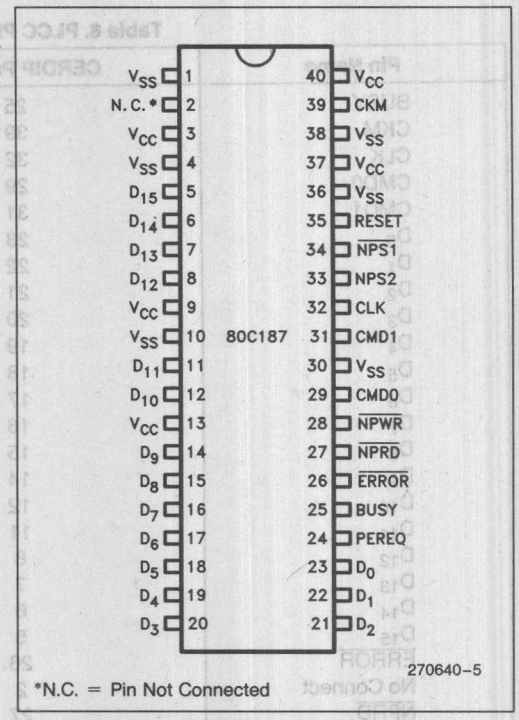


Figure 7. CERDIP Pin Configuration

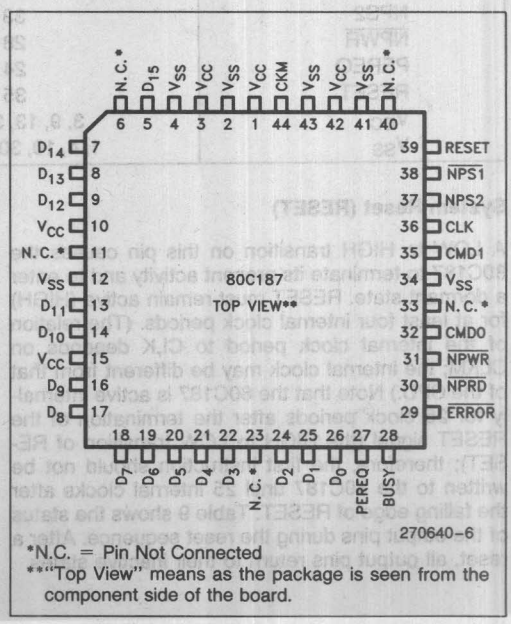


Figure 8. PLCC Pin Configuration

Table 8. PLCC Pin Cross-Reference

Pin Name	CERDIP Package	PLCC Package
BUSY	25	28
CKM	39	44
CLK	32	36
CMD0	29	32
CMD1	31	35
D_0	23	26
D_1	22	25
D_2	21	24
D_3	20	22
D_4	19	21
D_5	18	20
D_6	17	19
D_7	16	18
D_8	15	17
D_9	14	16
D_{10}	12	14
D_{11}	11	13
D_{12}	8	9
D_{13}	7	8
D_{14}	6	7
D_{15}	5	5
$\overline{ERROR}$	26	29
No Connect	2	6, 11, 23, 33, 40
$\overline{NPRD}$	27	30
$\overline{NPS1}$	34	38
NPS2	33	37
$\overline{NPWR}$	28	31
PEREQ	24	27
RESET	35	39
V_{CC}	3, 9, 13, 37, 40	1, 3, 10, 15, 42
V_{SS}	1, 4, 10, 30, 36, 38	2, 4, 12, 34, 41, 43

System Reset (RESET)

A LOW to HIGH transition on this pin causes the 80C187 to terminate its present activity and to enter a dormant state. RESET must remain active (HIGH) for at least four internal clock periods. (The relation of the internal clock period to CLK depends on CLKM; the internal clock may be different from that of the CPU.) Note that the 80C187 is active internally for 25 clock periods after the termination of the RESET signal (the HIGH to LOW transition of RESET); therefore, the first instruction should not be written to the 80C187 until 25 internal clocks after the falling edge of RESET. Table 9 shows the status of the output pins during the reset sequence. After a reset, all output pins return to their inactive states.

Table 9. Output Pin Status during Reset

Output Pin Name	Value during Reset
BUSY	HIGH
$\overline{ERROR}$	HIGH
PEREQ	LOW
D_{15}–D_0	TRI-STATE OFF

Processor Extension Request (PEREQ)

When active, this pin signals to the CPU that the 80C187 is ready for data transfer to/from its data FIFO. When there are more than five data transfers,

PEREQ is deactivated after the first three transfers and subsequently after every four transfers. This signal always goes inactive before BUSY goes inactive.

Busy Status (BUSY)

When active, this pin signals to the CPU that the 80C187 is currently executing an instruction. This pin is active HIGH. It should be connected to the 80C186's $\overline{\text{TEST}}$/BUSY pin. During the RESET sequence this pin is HIGH. The 80C186 uses this HIGH state to detect the presence of an 80C187.

Error Status ($\overline{\text{ERROR}}$)

This pin reflects the ES bit of the status register. When active, it indicates that an unmasked exception has occurred. This signal can be changed to inactive state only by the following instructions (without a preceding WAIT): FNINIT, FNCLEX, FNSTENV, FNSAVE, FLDCW, FLDENV, and FRSTOR. This pin should be connected to the $\overline{\text{ERROR}}$ pin of the CPU. $\overline{\text{ERROR}}$ can change state only when BUSY is active.

Data Pins (D_{15}–D_0)

These bidirectional pins are used to transfer data and opcodes between the CPU and 80C187. They are normally connected directly to the corresponding CPU data pins. Other buffers/drivers driving the local data bus must be disabled when the CPU reads from the NPX. High state indicates a value of one. D_0 is the least significant data bit.

Numeric Processor Write ($\overline{\text{NPWR}}$)

A signal on this pin enables transfers of data from the CPU to the NPX. This input is valid only when $\overline{\text{NPS1}}$ and NPS2 are both active.

Numeric Processor Read ($\overline{\text{NPRD}}$)

A signal on this pin enables transfers of data from the NPX to the CPU. This input is valid only when $\overline{\text{NPS1}}$ and NPS2 are both active.

Numeric Processor Selects ($\overline{\text{NPS1}}$ and NPS2)

Concurrent assertion of these signals indicates that the CPU is performing an escape instruction and enables the 80C187 to execute that instruction. No data transfer involving the 80C187 occurs unless the device is selected by these lines.

Command Selects (CMD0 and CMD1)

These pins along with the select pins allow the CPU to direct the operation of the 80C187.

System Power (V_{CC})

System power provides the +5V ±10% DC supply input. All V_{CC} pins should be tied together on the circuit board and local decoupling capacitors should be used between V_{CC} and V_{SS}.

System Ground (V_{SS})

All V_{SS} pins should be tied together on the circuit board and local decoupling capacitors should be used between V_{CC} and V_{SS}.

Processor Architecture

As shown by the block diagram (Figure 1), the 80C187 NPX is internally divided into three sections: the bus control logic (BCL), the data interface and control unit, and the floating-point unit (FPU). The FPU (with the support of the control unit which contains the sequencer and other support units) executes all numerics instructions. The data interface and control unit is responsible for the data flow to and from the FPU and the control registers, for receiving the instructions, decoding them, and sequencing the microinstructions, and for handling some of the administrative instructions. The BCL is responsible for CPU bus tracking and interface.

BUS CONTROL LOGIC

The BCL communicates solely with the CPU using I/O bus cycles. The BCL appears to the CPU as a special peripheral device. It is special in two respects: the CPU initiates I/O automatically when it encounters ESC instructions, and the CPU uses reserved I/O addresses to communicate with the BCL. The BCL does not communicate directly with memory. The CPU performs all memory access, transferring input operands from memory to the 80C187 and transferring outputs from the 80C187 to memory. A dedicated communication protocol makes possible high-speed transfer of opcodes and operands between the CPU and 80C187.

Table 10. Bus Cycles Definition

$\overline{NPS1}$	NPS2	CMD0	CMD1	$\overline{NPRD}$	$\overline{NPWR}$	Bus Cycle Type
x	0	x	x	x	x	80C187 Not Selected
1	x	x	x	x	x	80C187 Not Selected
0	1	0	0	1	0	Opcode Write to 80C187
0	1	0	0	0	1	CW or SW Read from 80C187
0	1	1	0	0	1	Read Data from 80C187
0	1	1	0	1	0	Write Data to 80C187
0	1	0	1	1	0	Write Exception Pointers
0	1	0	1	0	1	Reserved
0	1	1	1	0	1	Read Opcode Status
0	1	1	1	1	0	Reserved

DATA INTERFACE AND CONTROL UNIT

The data interface and control unit latches the data and, subject to BCL control, directs the data to the FIFO or the instruction decoder. The instruction decoder decodes the ESC instructions sent to it by the CPU and generates controls that direct the data flow in the FIFO. It also triggers the microinstruction sequencer that controls execution of each instruction. If the ESC instruction is FINIT, FCLEX, FSTSW, FSTSW AX, FSTCW, FSETPM, or FRSTPM, the control executes it independently of the FPU and the sequencer. The data interface and control unit is the one that generates the BUSY, PEREQ, and $\overline{ERROR}$ signals that synchronize 80C187 activities with the CPU.

FLOATING-POINT UNIT

The FPU executes all instructions that involve the register stack, including arithmetic, logical, transcendental, constant, and data transfer instructions. The data path in the FPU is 84 bits wide (68 significant bits, 15 exponent bits, and a sign bit) which allows internal operand transfers to be performed at very high speeds.

Bus Cycles

The pins $\overline{NPS1}$, NPS2, CMD0, CMD1, $\overline{NPRD}$ and $\overline{NPWR}$ identify bus cycles for the NPX. Table 10 defines the types of 80C187 bus cycles.

80C187 ADDRESSING

The $\overline{NPS1}$, NPS2, CMD0, and CMD1 signals allow the NPX to identify which bus cycles are intended for the NPX. The NPX responds to I/O cycles when the I/O address is 00F8H, 00FAH, 00FCH, or 00FEH. The correspondence betwen I/O addresses and control signals is defined by Table 11. To guarantee correct operation of the NPX, programs must not perform any I/O operations to these reserved port addresses.

Table 11. I/O Address Decoding

I/O Address (Hexadecimal)	80C187 Select and Command Inputs			
	NPS2	$\overline{NPS1}$	CMD1	CMD0
00F8	1	0	0	0
00FA	1	0	0	1
00FC	1	0	1	0
00FE	1	0	1	1

CPU/NPX SYNCHRONIZATION

The pins BUSY, PEREQ, and $\overline{\text{ERROR}}$ are used for various aspects of synchronization between the CPU and the NPX.

BUSY is used to synchronize instruction transfer from the CPU to the 80C187. When the 80C187 recognizes an ESC instruction, it asserts BUSY. For most ESC instructions, the CPU waits for the 80C187 to deassert BUSY before sending the new opcode.

The NPX uses the PEREQ pin of the CPU to signal that the NPX is ready for data transfer to or from its data FIFO. The NPX does not directly access memory; rather, the CPU provides memory access services for the NPX.

Once the CPU initiates an 80C187 instruction that has operands, the CPU waits for PEREQ signals that indicate when the 80C187 is ready for operand transfer. Once all operands have been transferred (or if the instruction has no operands) the CPU continues program execution while the 80C187 executes the ESC instruction.

In 8086/8087 systems, WAIT instructions are required to achieve synchronization of both commands and operands. The 80C187, however, does not require WAIT instructions. The WAIT or FWAIT instruction commonly inserted by high-level compilers and assembly-language programmers for exception synchronization is not treated as an instruction by the 80C186 and does not provide exception trapping. (Refer to the section "System Configuration for 8087-Compatible Exception Trapping".)

Once it has started to execute a numerics instruction and has transferred the operands from the CPU, the 80C187 can process the instruction in parallel with and independent of the host CPU. When the NPX detects an exception, it asserts the $\overline{\text{ERROR}}$ signal, which causes a CPU interrupt.

OPCODE INTERPRETATION

The CPU and the NPX use a bus protocol that adapts to the numerics opcode being executed. Only the NPX directly interprets the opcode. Some of the results of this interpretation are relevant to the CPU. The NPX records these results (opcode status information) in an internal 16-bit register. The 80C186 accesses this register only via reads from NPX port 00FEH. Tables 10 and 11 define the signal combinations that correspond to each of the following steps.

1. The CPU writes the opcode to NPX port 00F8H. This write can occur even when the NPX is busy or is signalling an exception. The NPX does not necessarily begin executing the opcode immediately.
2. The CPU reads the opcode status information from NPX port 00FEH.
3. The CPU initiates subsequent bus cycles according to the opcode status information. The opcode status information specifies whether to wait until the NPX is not busy, when to transfer exception pointers to port 00FCH, when to read or write operands and results at port 00FAH, etc.

For most instructions, the NPX does not start executing the previously transferred opcode until the CPU (guided by the opcode status information) first writes exception pointer information to port 00FCH of the NPX. This protocol is completely transparent to programmers.

Bus Operation

With respect to bus interface, the 80C187 is fully asynchronous with the CPU, even when it operates from the same clock source as the CPU. The CPU initiates a bus cycle for the NPX by activating both $\overline{\text{NPS1}}$ and NPS2, the NPX select signals. During the CLK period in which $\overline{\text{NPS1}}$ and NPS2 are activated, the 80C187 also examines the $\overline{\text{NPRD}}$ and $\overline{\text{NPRW}}$

input signals to determine whether the cycle is a read or a write cycle and examines the CMD0 and CMD1 inputs to determine whether an opcode, operand, or control/status register transfer is to occur. The 80C187 activates its BUSY output some time after the leading edge of the $\overline{NPRD}$ or $\overline{NPRW}$ signal. Input and ouput data are referenced to the trailing edges of the $\overline{NPRD}$ and $\overline{NPRW}$ signals.

The 80C187 activates the PEREQ signal when it is ready for data transfer. The 80C187 deactivates PEREQ automatically.

System Configuration

The 80C187 can be connected to the 80C186 CPU as shown by Figure 9. (Refer to the 80C186 Data Sheet for an explanation of the 80C186's signals.) This interface has the following characteristics:

- The 80C187's $\overline{NPS1}$, $\overline{ERROR}$, PEREQ, and BUSY pins are connected directly to the corresponding pins of the 80C186.
- The 80C186 pin $\overline{MCS3}/\overline{NPS}$ is connected to $\overline{NPS1}$; NPS2 is connected to V_{CC}. Note that if the 80C186 CPU's $\overline{DEN}$ signal is used to gate external data buffers, it must be combined with the $\overline{NPS}$ signal to insure numeric accesses will not activate these buffers.
- The $\overline{NPRD}$ and $\overline{NPRW}$ pins are connected to the $\overline{RD}$ and $\overline{WR}$ pins of the 80C186.
- CMD1 and CMD0 come from the latched A_2 and A_1 of the 80C186, respectively.
- The 80C187 BUSY output connects to the 80C186 $\overline{TEST}$/BUSY input. During RESET, the signal at the 80C187 BUSY output automatically programs the 80C186 to use the 80C187.
- The 80C187 can use the CLKOUT signal of the 80C186 to conserve board space when operating at 12.5 MHz or less. In this case, the 80C187 CKM input must be pulled HIGH. For operation in excess of 12.5 MHz, a double-frequency external oscillator for CLK input is needed. In this case, CKM must be pulled LOW.

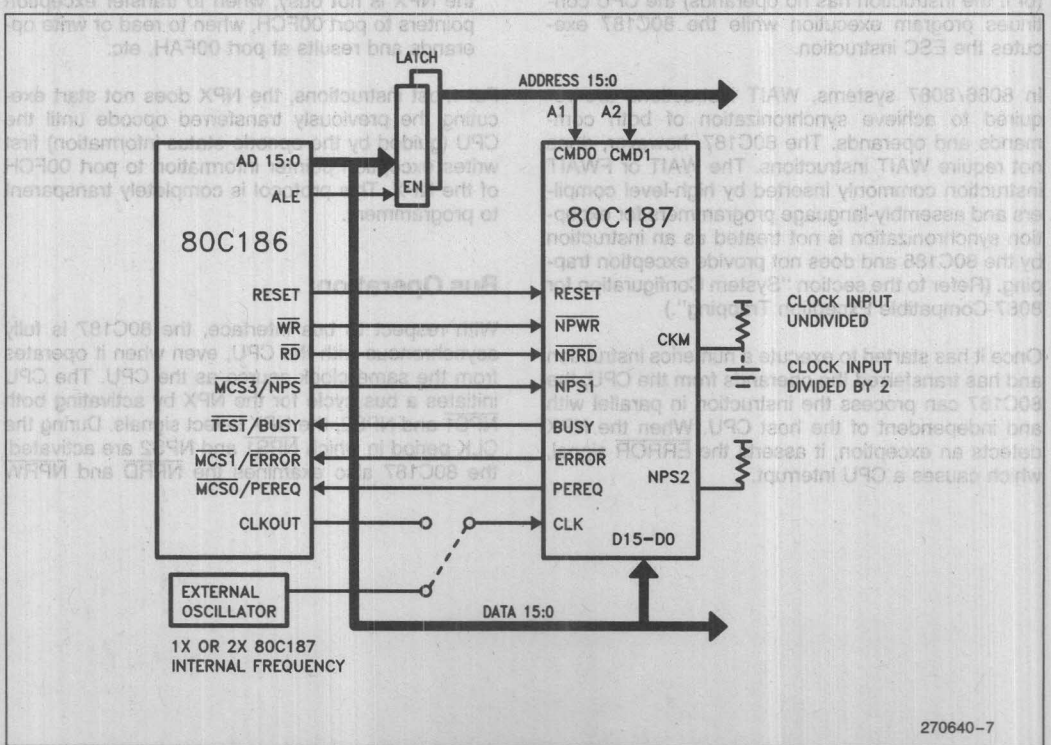
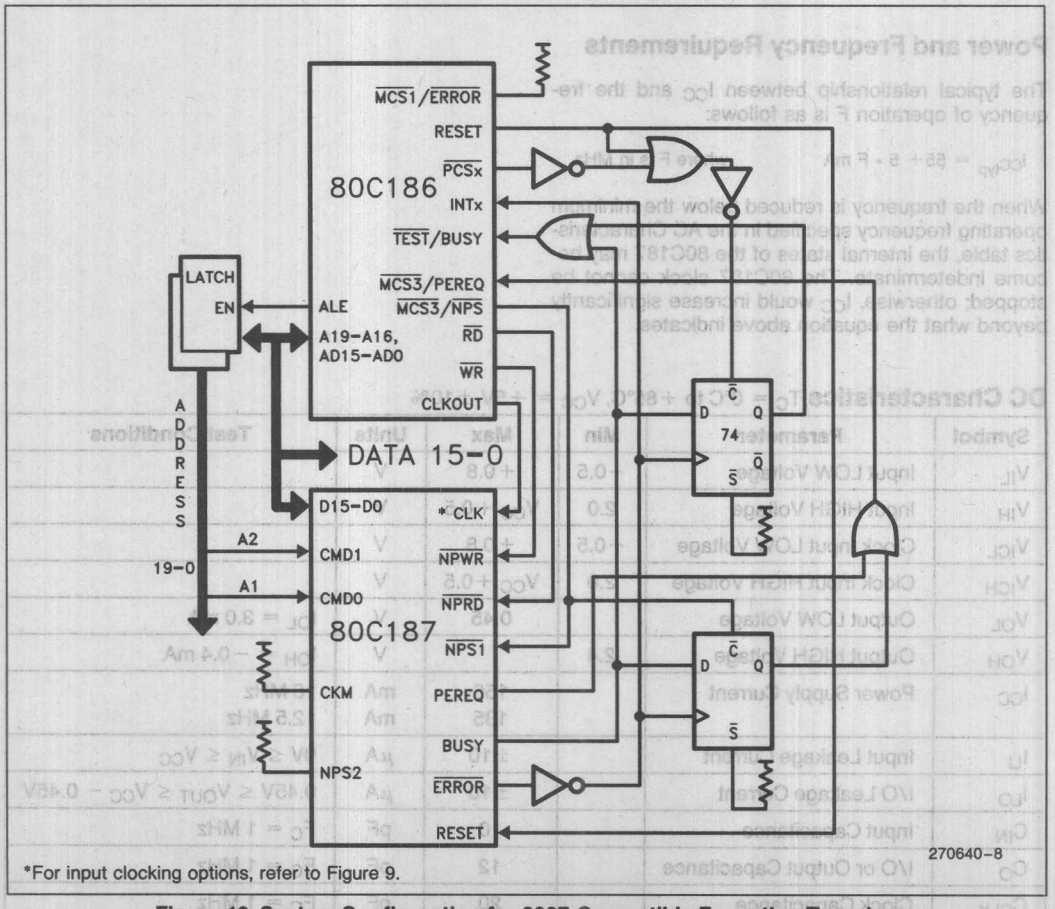


Figure 9. 80C186/80C187 System Configuration

System Configuration for 80186/80187-Compatible Exception Trapping

When the 80C187 $\overline{\text{ERROR}}$ output signal is connected directly to the 80C186 $\overline{\text{ERROR}}$ input, floating-point exceptions cause interrupt #16. However, existing software may be programmed to expect floating-point exceptions to be signalled over an external interrupt pin via an interrupt controller.

For exception handling compatible with the 80186/82188/8087, the 80C186 can be wired to recognize exceptions through an external interrupt pin, as Figure 10 shows. (Refer to the 80C186 Data Sheet for an explanation of the 80C186's signals.) With this arrangement, a flip-flop is needed to latch BUSY upon assertion of $\overline{\text{ERROR}}$. The latch can then be cleared during the exception-handler routine by forcing a $\overline{\text{PCS}}$ pin active. The latch must also be cleared at RESET in order for the 80C186 to work with the 80C187.



*For input clocking options, refer to Figure 9.

Figure 10. System Configuration for 8087-Compatible Exception Trapping

The typical relationship between I_{CC} and the frequency of operation F is as follows:

$I_{CC_{typ}} = 55 + 5 \cdot F$ mA where F is in MHz.

When the frequency is reduced below the minimum operating frequency specified in the AC Characteristics table, the internal states of the 80C187 may become indeterminate. The 80C187 clock cannot be stopped; otherwise, I_{CC} would increase significantly beyond what the equation above indicates.

DC Characteristics $T_C = 0°C$ to $+85°C$, $V_{CC} = +5V \pm 10\%$

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input LOW Voltage	−0.5	+0.8	V	
V_{IH}	Input HIGH Voltage	2.0	V_{CC} +0.5	V	
V_{ICL}	Clock Input LOW Voltage	−0.5	+0.8	V	
V_{ICH}	Clock Input HIGH Voltage	2.0	V_{CC} +0.5	V	
V_{OL}	Output LOW Voltage		0.45	V	I_{OL} = 3.0 mA
V_{OH}	Output HIGH Voltage	2.4		V	I_{OH} = −0.4 mA
I_{CC}	Power Supply Current		156 135	mA mA	16 MHz 12.5 MHz
I_{LI}	Input Leakage Current		±10	μA	$0V \le V_{IN} \le V_{CC}$
I_{LO}	I/O Leakage Current		±10	μA	$0.45V \le V_{OUT} \le V_{CC} - 0.45V$
C_{IN}	Input Capacitance		10	pF	F_C = 1 MHz
C_O	I/O or Output Capacitance		12	pF	F_C = 1 MHz
C_{CLK}	Clock Capacitance		20	pF	F_C = 1 MHz

AC Characteristics

T_C = 0°C to +85°C, V_{CC} = 5V ±10%
All timings are measured at 1.5V unless otherwise specified

Symbol	Parameter	12.5 MHz		16 MHz		Test Conditions
		Min (ns)	Max (ns)	Min (ns)	Max (ns)	
T_{dvwh} (t6)	Data Setup to $\overline{NPWR}$	43		33		
T_{whdx} (t7)	Data Hold from $\overline{NPWR}$	14		14		
T_{rlrh} (t8)	$\overline{NPRD}$ Active Time	59		54		
T_{wlwh} (t9)	$\overline{NPWR}$ Active Time	59		54		
T_{avwl} (t10)	Command Valid to $\overline{NPWR}$	0		0		
T_{avrl} (t11)	Command Valid to $\overline{NPRD}$	0		0		
T_{mhrl} (t12)	Min Delay from PEREQ Active to $\overline{NPRD}$ Active	40		30		
T_{whax} (t18)	Command Hold from $\overline{NPWR}$	12		8		
T_{rhax} (t19)	Command Hold from $\overline{NPRD}$	12		8		
T_{ivcl} (t20)	$\overline{NPRD}$, $\overline{NPWR}$, RESET to CLK Setup Time	46		38		Note 1
T_{clih} (t21)	$\overline{NPRD}$, $\overline{NPWR}$, RESET from CLK Hold Time	26		18		Note 1
T_{rscl} (t24)	RESET to CLK Setup	21		19		Note 1
T_{clrs} (t25)	RESET from CLK Hold	14		9		Note 1
T_{cmdi} (t26)	Command Inactive Time					
	Write to Write	69		59		
	Read to Read	69		59		
	Read to Write	69		59		
	Write to Read	69		59		

NOTE:
1. This is an asynchronous input. This specification is given for testing purposes only, to assure recognition at a specific CLK edge.

Timing Responses

All timings are measured at 1.5V unless otherwise specified

Symbol	Parameter	12.5 MHz		16 MHz		Test Conditions
		Min (ns)	Max (ns)	Min (ns)	Max (ns)	
T_{rhqz} (t27)	$\overline{NPRD}$ Inactive to Data Float*		18		18	Note 2
T_{rlqv} (t28)	$\overline{NPRD}$ Active to Data Valid		50		45	Note 3
T_{ilbh} (t29)	$\overline{ERROR}$ Active to Busy Inactive	104		104		Note 4
T_{wlbv} (t30)	$\overline{NPWR}$ Active to Busy Active		80		60	Note 4
T_{klml} (t31)	$\overline{NPRD}$ or $\overline{NPWR}$ Active to PEREQ Inactive		80		60	Note 5
T_{rhqh} (t32)	Data Hold from $\overline{NPRD}$ Inactive	2		2		Note 3
T_{rlbh} (t33)	RESET Inactive to BUSY Inactive		80		60	

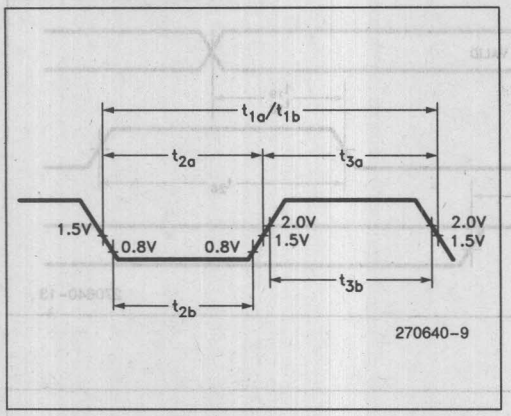
NOTES:
*The data float delay is not tested.
2. The float condition occurs when the measured output current is less than I_{OL} on D_{15}–D_0.
3. D_{15}–D_0 loading: C_L = 100 pF.
4. BUSY loading: C_L = 100 pF.
5. On last data transfer of numeric instruction.

Clock Timings

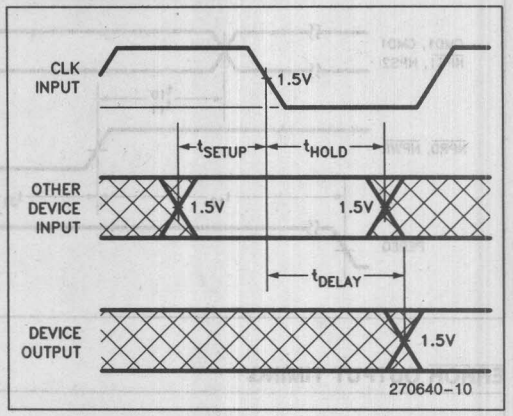
Symbol	Parameter		12.5 MHz		16 MHz*		Test Conditions
			Min (ns)	Max (ns)	Min (ns)	Max (ns)	
T_{clcl} (t1a)	CLK Period	CKM = 1	80	250	N/A	N/A	Note 6
(t1B)		CKM = 0	40	125	31.25	125	Note 6
T_{clch} (t2a)	CLK Low Time	CKM = 1	35		N/A		Note 6
(t2b)		CKM = 0	9		7		Note 7
T_{chcl} (t3a)	CLK High Time	CKM = 1	35		N/A		Note 6
(t3b)		CKM = 0	13		9		Note 8
T_{ch2ch1}(t4)				10		8	Note 9
T_{ch1ch2}(t5)				10		8	Note 10

NOTES:
*16 MHz operation is available only in divide-by-2 mode (CKM strapped LOW).
6. At 1.5V
7. At 0.8V
8. At 2.0V
9. CKM = 1: 3.7V to 0.8V at 16 MHz, 3.5V to 1.0V at 12.5 MHz
10. CKM = 1: 0.8V to 3.7V at 16 MHz, 1.0V to 3.5V at 12.5 MHz

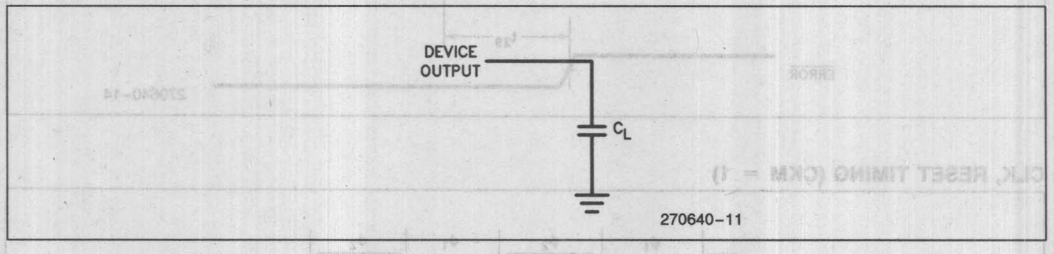
AC DRIVE AND MEASUREMENT POINTS—CLK INPUT



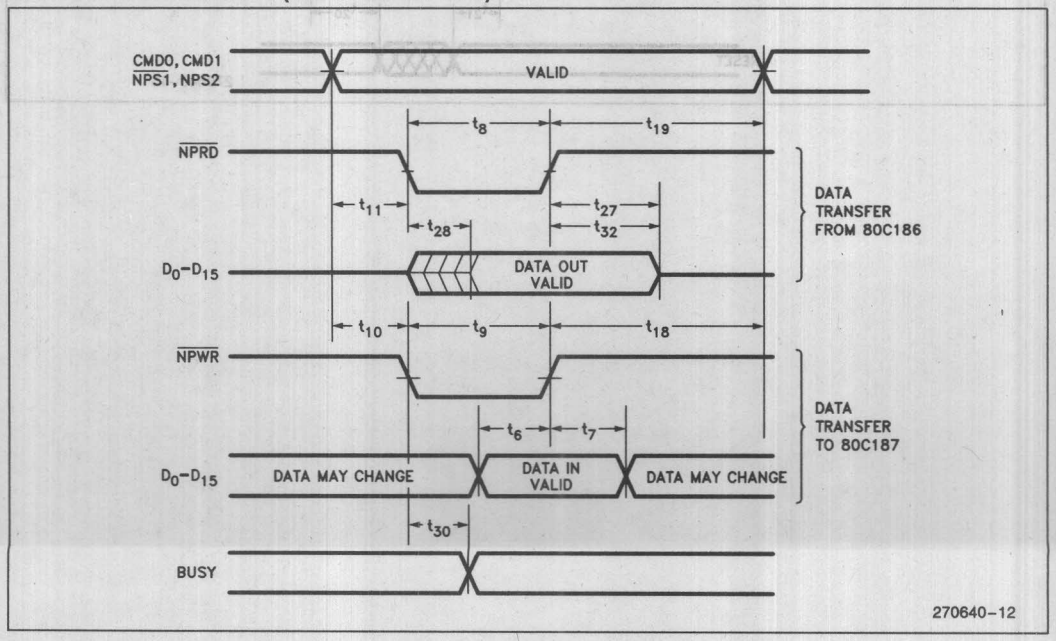
AC SETUP, HOLD, AND DELAY TIME MEASUREMENTS—GENERAL



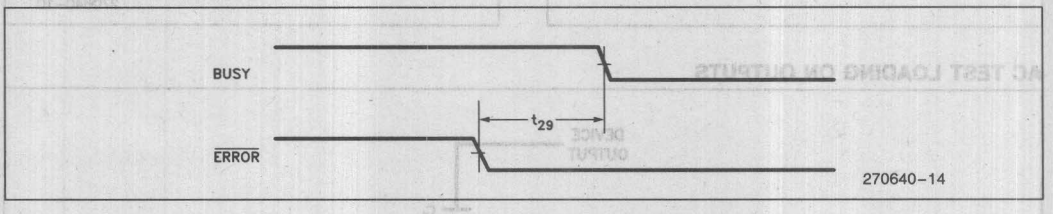
AC TEST LOADING ON OUTPUTS



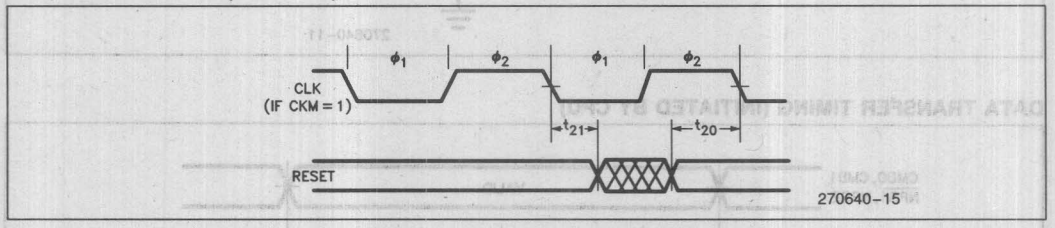
DATA TRANSFER TIMING (INITIATED BY CPU)

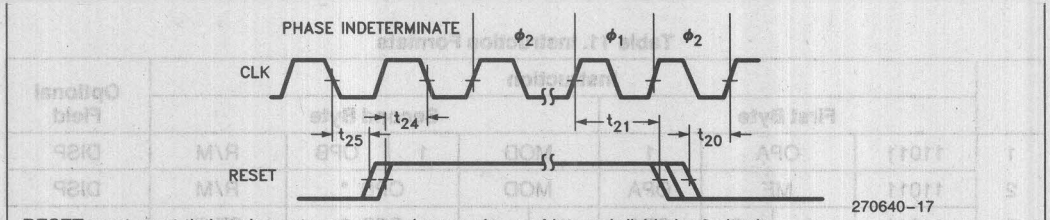


$\overline{\text{ERROR}}$ OUTPUT TIMING



CLK, RESET TIMING (CKM = 1)

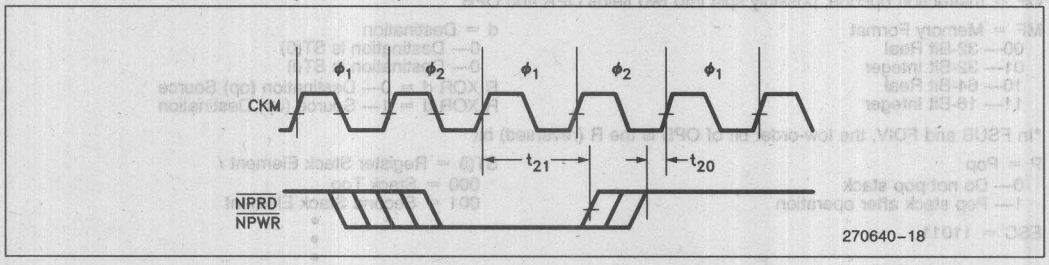




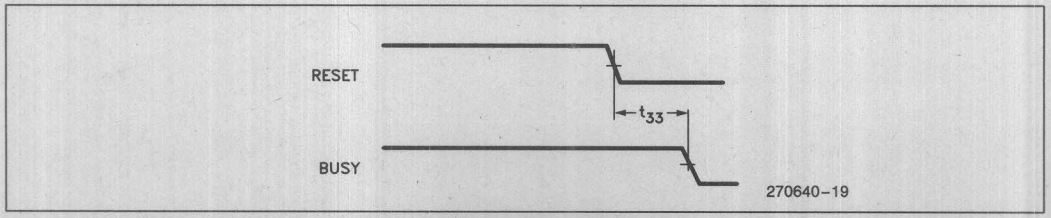
RESET must meet timing shown to guarantee known phase of internal divide by 2 circuits.

NOTE:
RESET, $\overline{\text{NPWR}}$, $\overline{\text{NPRD}}$ inputs are asynchronous to CLK. Timing requirements are given for testing purposes only, to assure recognition at a specific CLK edge.

CLK, $\overline{\text{NPRD}}$, $\overline{\text{NPWR}}$ TIMING (CKM = 0)



RESET, BUSY TIMING



80C187 EXTENSIONS TO THE CPU's INSTRUCTION SET

Instructions for the 80C187 assume one of the five forms shown in Table 11. In all cases, instructions are at least two bytes long and begin with the bit pattern 11011B, which identifies the ESCAPE class of instruction. Instructions that refer to memory operands specify addresses using the CPU's addressing modes.

MOD (Mode field) and R/M (Register/Memory specifier) have the same interpretation as the corresponding fields of CPU instructions (refer to Programmer's Reference Manual for the CPU). The DISP (displacement) is optionally present in instructions that have MOD and R/M fields. Its presence depends on the values of MOD and R/M, as for instructions of the CPU.

The instruction summaries that follow assume that the instruction has been prefetched, decoded, and is ready for execution; that bus cycles do not require wait states; that there are no local bus HOLD requests delaying processor access to the bus; and that no exceptions are detected during instruction execution. Timings are given in internal 80C187 clocks and include the time for opcode and data transfer between the CPU and the NPX. If the instruction has MOD and R/M fields that call for both base and index registers, add one clock.

Table 11. Instruction Formats

	Instruction									Optional Field
	First Byte				Second Byte					
1	11011	OPA		1	MOD		1	OPB	R/M	DISP
2	11011	MF		OPA	MOD		OPB *		R/M	DISP
3	11011	d	P	OPA	1	1	OPB *		ST (i)	
4	11011	0	0	1	1	1	1	OP		
5	11011	0	1	1	1	1	1	OP		
	15–11	10	9	8	7	6	5	4 3	2 1 0	

NOTES:
OP = Instruction opcode, possibly split into two fields OPA and OPB

MF = Memory Format
- 00— 32-Bit Real
- 01— 32-Bit Integer
- 10— 64-Bit Real
- 11— 16-Bit Integer

d = Destination
- 0— Destination is ST(0)
- 0— Destination is ST(i)

R XOR d = 0— Destination (op) Source
R XOR d = 1— Source (op) Destination

*In FSUB and FDIV, the low-order bit of OPB is the R (reversed) bit

P = Pop
- 0— Do not pop stack
- 1— Pop stack after operation

ESC = 11011

ST(i) = Register Stack Element *i*
- 000 = Stack Top
- 001 = Second Stack Element
- •
- •
- •
- 111 = Eighth Stack Element

80C187 Extensions to the 80C186 Instruction Set

Instruction	Encoding: Byte 0	Encoding: Byte 1	Encoding: Optional Bytes 2–3	Clock Count Range: 32-Bit Real	32-Bit Integer	64-Bit Real	16-Bit Integer
DATA TRANSFER							
FLD = Load[a]							
Integer/real memory to ST(0)	ESC MF 1	MOD 000 R/M	DISP	40	65–72	59	67–71
Long integer memory to ST(0)	ESC 111	MOD 101 R/M	DISP		90–101		
Extended real memory to ST(0)	ESC 011	MOD 101 R/M	DISP		74		
BCD memory to ST(0)	ESC 111	MOD 100 R/M	DISP		296–305		
ST(i) to ST(0)	ESC 001	11000 ST(i)			16		
FST = Store							
ST(0) to integer/real memory	ESC MF 1	MOD 010 R/M	DISP	58	93–107	73	80–93
ST(0) to ST(i)	ESC 101	11010 ST(i)			13		
FSTP = Store and Pop							
ST(0) to integer/real memory	ESC MF 1	MOD 011 R/M	DISP	58	93–107	73	80–93
ST(0) to long integer memory	ESC 111	MOD 111 R/M	DISP		116–133		
ST(0) to extended real	ESC 011	MOD 111 R/M	DISP		83		
ST(0) to BCD memory	ESC 111	MOD 110 R/M	DISP		542–564		
ST(0) to ST(i)	ESC 101	11001 ST (i)			14		
FXCH = Exchange							
ST(i) and ST(0)	ESC 001	11001 ST(i)			20		
COMPARISON							
FCOM = Compare							
Integer/real memory to ST(0)	ESC MF 0	MOD 010 R/M	DISP	48	78–85	67	77–81
ST(i) to ST(0)	ESC 000	11010 ST(i)			26		
FCOMP = Compare and pop							
Integer/real memory to ST	ESC MF 0	MOD 011 R/M	DISP	48	78–85	67	77–81
ST(i) to ST(0)	ESC 000	11011 ST(i)			28		
FCOMPP = Compare and pop twice							
ST(1) to ST(0)	ESC 110	1101 1001			28		
FTST = Test ST(0)	ESC 001	1110 0100			30		
FUCOM = Unordered compare	ESC 101	11100 ST(i)			26		
FUCOMP = Unordered compare and pop	ESC 101	11101 ST(i)			28		
FUCOMPP = Unordered compare and pop twice	ESC 010	1110 1001			28		
FXAM = Examine ST(0)	ESC 001	11100101			32-40		
CONSTANTS							
FLDZ = Load +0.0 into ST(0)	ESC 001	1110 1110			22		
FLD1 = Load +1.0 into ST(0)	ESC 001	1110 1000			26		
FLDPI = Load pi into ST(0)	ESC 001	1110 1011			42		
FLDL2T = Load $\log_2(10)$ into ST(0)	ESC 001	1110 1001			42		

Shaded areas indicate instructions not available in 8087.

NOTE:
a. When loading single- or double-precision zero from memory, add 5 clocks.

80C187 Extensions to the 80C186 Instruction Set (Continued)

Instruction	Encoding			Clock Count Range			
	Byte 0	Byte 1	Optional Bytes 2–3	32-Bit Real	32-Bit Integer	64-Bit Real	16-Bit Integer
CONSTANTS (Continued)							
FLDL2E = Load $\log_2(e)$ into ST(0)	ESC 001	1110 1010			42		
FLDLG2 = Load $\log_{10}(2)$ into ST(0)	ESC 001	1110 1100			43		
FLDLN2 = Load $\log_e(2)$ into ST(0)	ESC 001	1110 1101			43		
ARITHMETIC							
FADD = Add							
Integer/real memory with ST(0)	ESC MF 0	MOD 000 R/M	DISP	44–52	77–92	65–73	77–91
ST(i) and ST(0)	ESC d P 0	11000 ST(i)			25–33[b]		
FSUB = Subtract							
Integer/real memory with ST(0)	ESC MF 0	MOD 10 R R/M	DISP	44–52	77–92	65–73	77–91[c]
ST(i) and ST(0)	ESC d P 0	1110 R R/M			28–36[d]		
FMUL = Multiply							
Integer/real memory with ST(0)	ESC MF 0	MOD 001 R/M	DISP	47–57	81–102	68–93	82–93
ST(i) and ST(0)	ESC d P 0	1100 1 R/M			31–59[e]		
FDIV = Divide							
Integer/real memory with ST(0)	ESC MF 0	MOD 11 R R/M	DISP	108	140–147[f]	128	142–146[g]
ST(i) and ST(0)	ESC d P 0	1111 R R/M			90[h]		
FSQRT[i] = Square root	ESC 001	1111 1010			124–131		
FSCALE = Scale ST(0) by ST(1)	ESC 001	1111 1101			69–88		
FPREM = Partial remainder of ST(0) ÷ ST(1)	ESC 001	1111 1000			76–157		
FPREM1 = Partial remainder (IEEE)	ESC 001	1111 0101			97–187		
FRNDINT = Round ST(0) to integer	ESC 001	1111 1100			68–82		
FXTRACT = Extract components of ST(0)	ESC 001	1111 0100			72–78		
FABS = Absolute value of ST(0)	ESC 001	1110 0001			24		
FCHS = Change sign of ST(0)	ESC 001	1110 0000			26–27		

Shaded areas indicate instructions not available in 8087.

NOTES:
b. Add 3 clocks to the range when d = 1.
c. Add 1 clock to **each** range when R = 1.
d. Add 3 clocks to the range when d = 0.
e. typical = 54 (When d = 0, 48–56, typical = 51).
f. Add 1 clock to the range when R = 1.
g. 153–159 when R = 1.
h. Add 3 clocks to the range when d = 1.
i. $-0 \leq ST(0) \leq +\infty$.

80C187 Extensions to the 80C186 Instruction Set (Continued)

Instruction	Encoding			Clock Count Range
	Byte 0	Byte 1	Optional Bytes 2–3	
TRANSCENDENTAL				
FCOS = Cosine of ST(0)	ESC 001	1111 1111		125–774j
FPTAN[k] = Partial tangent of ST(0)	ESC 001	1111 0010		193–499j
FPATAN = Partial arctangent	ESC 001	1111 0011		316–489
FSIN = Sine of ST(0)	ESC 001	1111 1110		124–773j
FSINCOS = Sine and cosine of ST(0)	ESC 001	1111 1011		196–811j
F2XM1[l] = $2^{ST(0)} - 1$	ESC 001	1111 0000		213–478
FYL2X[m] = ST(1) * $\log_2(ST(0))$	ESC 001	1111 0001		122–540
FYL2XP1[n] = ST(1) * $\log_2(ST(0) + 1.0)$	ESC 001	1111 1001		259–549
PROCESSOR CONTROL				
FINIT = Initialize NPX	ESC 011	1110 0011		35
FSTSW AX = Store status word	ESC 111	1110 0000		17
FLDCW = Load control word	ESC 001	MOD 101 R/M	DISP	23
FSTCW = Store control word	ESC 001	MOD 111 R/M	DISP	21
FSTSW = Store status word	ESC 101	MOD 111 R/M	DISP	21
FCLEX = Clear exceptions	ESC 011	1110 0010		13
FSTENV = Store environment	ESC 001	MOD 110 R/M	DISP	146
FLDENV = Load environment	ESC 001	MOD 100 R/M	DISP	113
FSAVE = Save state	ESC 101	MOD 110 R/M	DISP	550
FRSTOR = Restore state	ESC 101	MOD 100 R/M	DISP	482
FINCSTP = Increment stack pointer	ESC 001	1111 0111		23
FDECSTP = Decrement stack pointer	ESC 001	1111 0110		24
FFREE = Free ST(i)	ESC 101	1100 0 ST(i)		20
FNOP = No operations	ESC 001	1101 0000		14

Shaded areas indicate instructions not available in 8087.

NOTES:
j. These timings hold for operands in the range $|x| < \pi/4$. For operands not in this range, up to 78 clocks may be needed to reduce the operand.
k. $0 \leq |ST(0)| < 2^{63}$.
l. $-1.0 \leq ST(0) \leq 1.0$.
m. $0 \leq ST(0) < \infty$, $-\infty < ST(1) < +\infty$.
n. $0 \leq |ST(0)| < (2 - \sqrt{(2)})/2$, $-\infty < ST(1) < +\infty$.

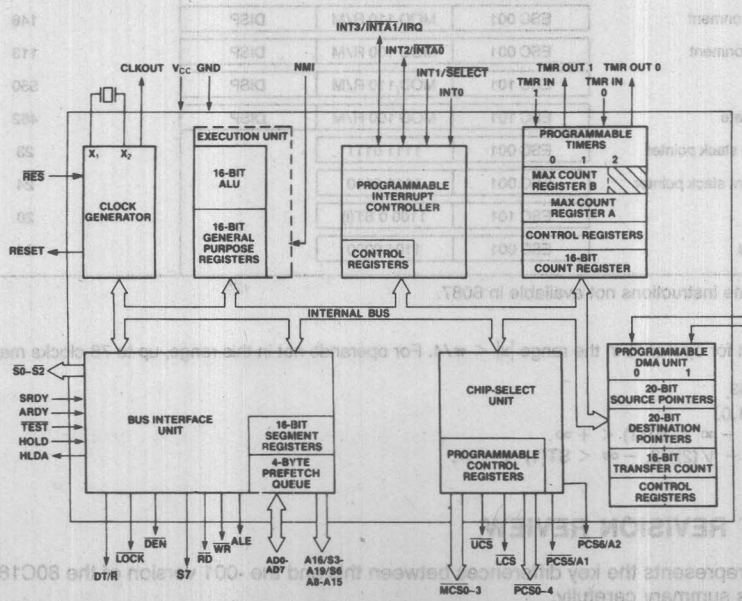
DATA SHEET REVISION REVIEW

The following list represents the key differences between this and the -001 version of the 80C187 data sheet. Please review this summary carefully.

1. Figure 10, titled "System Configuration for 8087—Compatible Exception Trapping", was replaced with a revised schematic. The previous configuration was faulty. Updated timing diagrams on Data Transfer Timing, Error Output, and RESET/BUSY.

- **16-Bit Internal Architecture with 8-Bit Data Bus Interface**
- **High-Performance 8 MHz Processor**
  - **2 MByte/Sec Bus Bandwidth Interface @8 MHz**
- **Direct Addressing Capability to 1 MByte of Memory and 64 KByte I/O**
- **Through 8087 Interface**
- **Available in 68 Pin:**
  - **Ceramic Leadless Chip Carrier (LCC)**
  - **Ceramic Pin Grid Array (PGA)**
  - **Plastic Leaded Chip Carrier (PLCC)**

  (See Packaging Outlines and Dimensions, Order #231369)
- **Available in EXPRESS**
  - **Standard Temperature with Burn-In**
  - **Extended Temperature Range (−40°C to +85°C)**



210706-1

Figure 1. 80188 Block Diagram

October 1989
Order Number: 210706-011

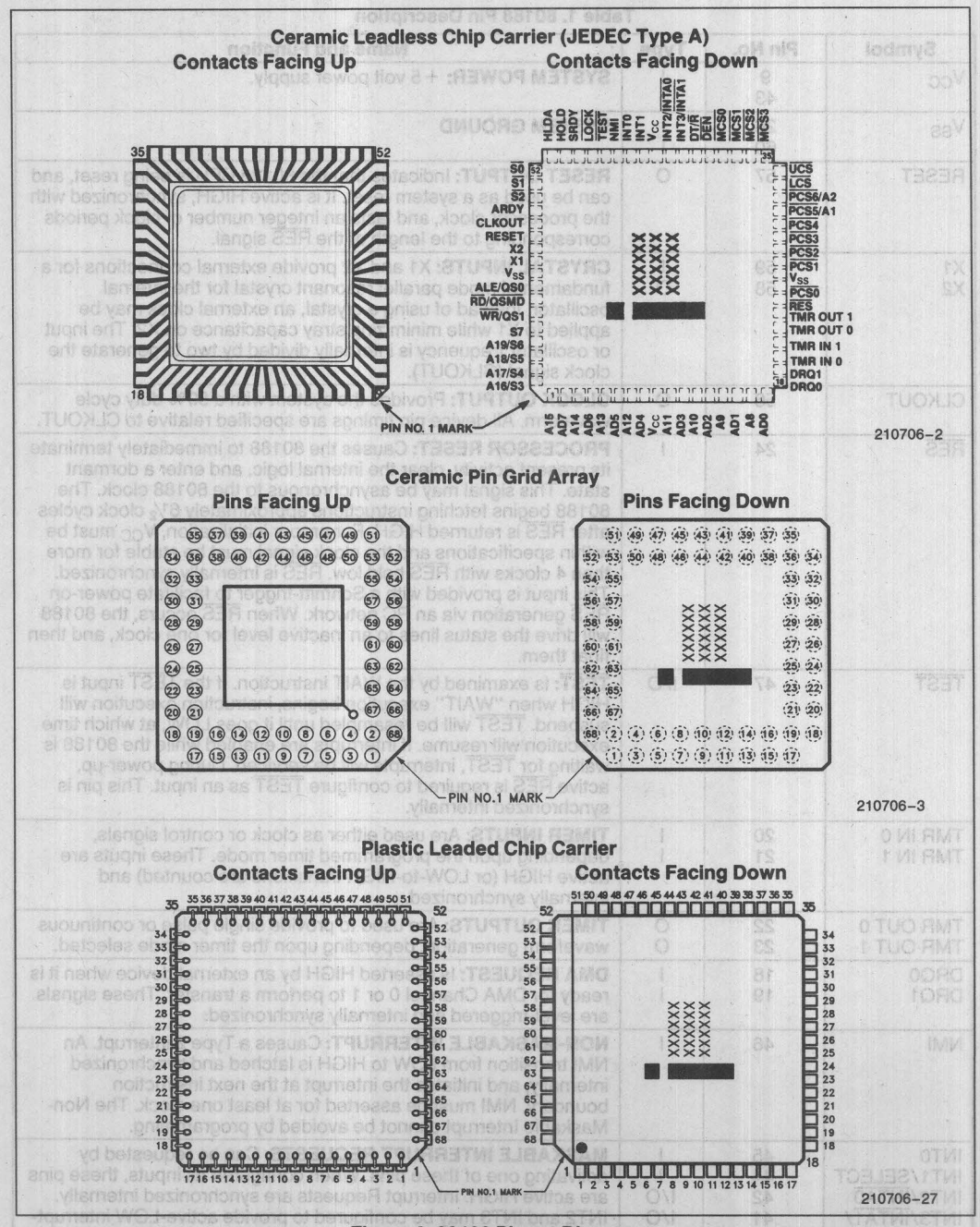


Figure 2. 80188 Pinout Diagram

Table 1. 80188 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	9 43	I I	**SYSTEM POWER:** +5 volt power supply.
V_{SS}	26 60	I I	**SYSTEM GROUND**
RESET	57	O	**RESET OUTPUT:** Indicates that the 80188 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal.
X1 X2	59 58	I O	**CRYSTAL INPUTS:** X1 and X2 provide external connections for a fundamental mode parallel resonant crystal for the internal oscillator. Instead of using a crystal, an external clock may be applied to X1 while minimizing stray capacitance on X2. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	**CLOCK OUTPUT:** Provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT.
$\overline{RES}$	24	I	**PROCESSOR RESET:** Causes the 80188 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80188 clock. The 80188 begins fetching instructions approximately 6½ clock cycles after $\overline{RES}$ is returned HIGH. For proper initialization, V_{CC} must be within specifications and the clock signal must be stable for more than 4 clocks with $\overline{RES}$ held low. $\overline{RES}$ is internally synchronized. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network. When $\overline{RES}$ occurs, the 80188 will drive the status lines to an inactive level for one clock, and then float them.
$\overline{TEST}$	47	I/O	**$\overline{TEST}$:** Is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when "WAIT" execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80188 is waiting for $\overline{TEST}$, interrupts will be serviced. During power-up, active $\overline{RES}$ is required to configure $\overline{TEST}$ as an input. This pin is synchronized internally.
TMR IN 0 TMR IN 1	20 21	I I	**TIMER INPUTS:** Are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized.
TMR OUT 0 TMR OUT 1	22 23	O O	**TIMER OUTPUTS:** Are used to provide single pulse or continuous waveform generation, depending upon the timer mode selected.
DRQ0 DRQ1	18 19	I I	**DMA REQUEST:** Is asserted HIGH by an external device when it is ready for DMA Channel 0 or 1 to perform a transfer. These signals are level-triggered and internally synchronized.
NMI	46	I	**NON-MASKABLE INTERRUPT:** Causes a Type 2 interrupt. An NMI transition from LOW to HIGH is latched and synchronized internally, and initiates the interrupt at the next instruction boundary. NMI must be asserted for at least one clock. The Non-Maskable Interrupt cannot be avoided by programming.
INT0 INT1/SELECT INT2/$\overline{INTA0}$ INT3/$\overline{INTA1}$/ IRQ	45 44 42 41	I I I/O I/O	**MASKABLE INTERRUPT REQUESTS:** Can be requested by activating one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowledged. When Slave Mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).

AD2 AD1 AD0	13 15 17	I/O I/O I/O	
A15 A14 A13 A12 A11 A10 A9 A8	1 3 5 7 10 12 14 16	O O O O O O O O	**ADDRESS-ONLY BUS (8-15):** Containing valid address from T_1-T_4. The bus is active HIGH.
S7	64	O	This signal is HIGH to indicate that the 80188 has an 8-bit data bus. S7 floats during HOLD.
ALE/QS0	61	O	**ADDRESS LATCH ENABLE/QUEUE STATUS 0:** Is provided by the 80188 to latch the address. ALE is active HIGH. Addresses are guaranteed to be valid on the trailing edge of ALE. The ALE rising edge is generated off the rising edge of the CLKOUT immediately preceding T_1 of the associated bus cycle, effectively one-half clock cycle earlier than in the 8088. The trailing edge is generated off the CLKOUT rising edge in T_1 as in the 8088. Note that ALE is never floated.
$\overline{WR}$/QS1	63	O	**WRITE STROBE/QUEUE STATUS 1:** Indicates that the data on the bus is to be written into a memory or an I/O device. $\overline{WR}$ is active for T_2, T_3, and T_W of any write cycle. It is active LOW, and floats during HOLD. When the 80188 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction.

QS1	QS0	Queue Operation
0	0	No Queue Operation
0	1	First Opcode Byte Fetched from the Queue
1	1	Subsequent Byte Fetched from the Queue
1	0	Empty the Queue

Table 1. 80188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{RD}/\overline{QSMD}$	62	I/O	**READ STROBE:** Is an active LOW signal which indicates that the 80188 is performing a memory or I/O read cycle. It is guaranteed not to go LOW before the A/D bus is floated. An internal pull-up ensures that $\overline{RD}$ is HIGH during RESET. Following RESET the pin is sampled to determine whether the 80188 is to provide ALE, $\overline{RD}$, and $\overline{WR}$, or queue status information. To enable Queue Status Mode, $\overline{RD}$ must be connected to GND. $\overline{RD}$ will float during bus HOLD.
ARDY	55	I	**ASYNCHRONOUS READY:** Informs the 80188 that the addressed memory space or I/O device will complete a data transfer. The ARDY pin accepts a rising edge that is asynchronous to CLKOUT and is active HIGH. The falling edge of ARDY must be synchronized to the 80188 clock. Connecting ARDY HIGH will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the SRDY pin.
SRDY	49	I	**SYNCHRONOUS READY:** Informs the 80188 that the addressed memory space or I/O device will complete a data transfer. The SRDY pin accepts an active-HIGH input synchronized to CLKOUT. The use of SRDY allows a relaxed system timing over ARDY. This is accomplished by elimination of the one-half clock cycle required to internally synchronize the ARDY input signal. Connecting SRDY high will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the ARDY pin.
$\overline{LOCK}$	48	O	**$\overline{LOCK}$:** Output indicates that other system bus masters are not to gain control of the system bus while $\overline{LOCK}$ is active LOW. The $\overline{LOCK}$ signal is requested by the LOCK prefix instruction and is activated at the beginning of the first data cycle associated with the instruction following the LOCK prefix. It remains active until the completion of that instruction. No instruction prefetching will occur while $\overline{LOCK}$ is asserted. When executing more than one LOCK instruction, always make sure there are 4 bytes of code between the end of the first $\overline{LOCK}$ instruction and the start of the second LOCK instruction. $\overline{LOCK}$ is active LOW, is driven HIGH for one clock during RESET, and then floated.
$\overline{S0}$ $\overline{S1}$ $\overline{S2}$	52 53 54	O O O	**BUS CYCLE STATUS $\overline{S0}$–$\overline{S2}$:** Are encoded to provide bus-transaction information:

80188 Bus Cycle Status Information

$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	Bus Cycle Initiated
0	0	0	Interrupt Acknowledge
0	0	1	Read I/O
0	1	0	Write I/O
0	1	1	Halt
1	0	0	Instruction Fetch
1	0	1	Read Data from Memory
1	1	0	Write Data to Memory
1	1	1	Passive (no bus cycle)

The status pins float during HOLD.
$\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator.

Table 1. 80188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
HOLD (input) HLDA (output)	50 51	I O	**HOLD:** Indicates that another bus master is requesting the local bus. The HOLD input is active HIGH. HOLD may be asynchronous with respect to the 80188 clock. The 80188 will issue a HLDA in response to a HOLD request at the end of T_4 or T_i. Simultaneous with the issuance of HLDA, the 80188 will float the local bus and control lines. After HOLD is detected as being LOW, the 80188 will lower HLDA. When the 80188 needs to run another bus cycle, it will again drive the local bus and control lines.
$\overline{UCS}$	34	O	**UPPER MEMORY CHIP SELECT:** Is an active LOW output whenever a memory reference is made to the defined upper portion (1K–256K block) of memory. This line is not floated during bus HOLD. The address range activating $\overline{UCS}$ is software programmable.
$\overline{LCS}$	33	O	**LOWER MEMORY CHIP SELECT:** Is active LOW whenever a memory reference is made to the defined lower portion (1K–256K) of memory. This line is not floated during bus HOLD. The address range activating $\overline{LCS}$ is software programmable.
$\overline{MCS0}$ $\overline{MCS1}$ $\overline{MCS2}$ $\overline{MCS3}$	38 37 36 35	O O O O	**MID-RANGE MEMORY CHIP SELECT SIGNALS:** Are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines are not floated during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable.
$\overline{PCS0}$ $\overline{PCS1}$ $\overline{PCS2}$ $\overline{PCS3}$ $\overline{PCS4}$	25 27 28 29 30	O O O O O	**PERIPHERAL CHIP SELECT SIGNALS 0–4:** Are active LOW when a reference is made to the defined peripheral area (64K byte I/O space). These lines are not floated during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	**PERIPHERAL CHIP SELECT 5 or LATCHED A1:** May be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software programmable. $\overline{PCS5}$/A1 does not float during bus HOLD. When programmed to provide latched A1, this pin will retain the previously latched value during HOLD.
$\overline{PCS6}$/A2	32	O	**PERIPHERAL CHIP SELECT 6 or LATCHED A2:** May be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software-programmable. $\overline{PCS6}$/A2 does not float during bus HOLD. When programmed to provide latched A2, this pin will retain the previously latched value during HOLD.
DT/$\overline{R}$	40	O	**DATA TRANSMIT/RECEIVE:** Controls the direction of data flow through an external data bus transceiver. When LOW, data is transferred to the 80188. When HIGH the 80188 places write data on the data bus.
$\overline{DEN}$	39	O	**DATA ENABLE:** Is provided as a data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access. $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state. During RESET, $\overline{DEN}$ is driven HIGH for one clock, then floated. $\overline{DEN}$ also floats during bus HOLD.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the 80188. The 80188 is a very high integration 8-bit microprocessor. It combines 15–20 of the most common microprocessor system components onto one chip while providing twice the performance of the standard 8088. The 80188 is object code compatible with the 8086, 8088 microprocessors and adds 10 new instruction types to the 8086, 8088 instruction set.

80188 BASE ARCHITECTURE

The 8086, 8088, 80186, 80188 and 80286 family all contain the same basic set of registers, instructions, and addressing modes. The 80188 processor is upward compatible with the 8086, 8088, 80186, and 80286 CPUs.

Register Set

The 80188 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

GENERAL REGISTERS

Eight 16-bit general purpose registers may be used for arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

SEGMENT REGISTERS

Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

BASE AND INDEX REGISTERS

Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

STATUS AND CONTROL REGISTERS

Two 16-bit special purpose registers record or alter certain aspects of the 80188 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

STATUS WORD DESCRIPTION

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80188 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

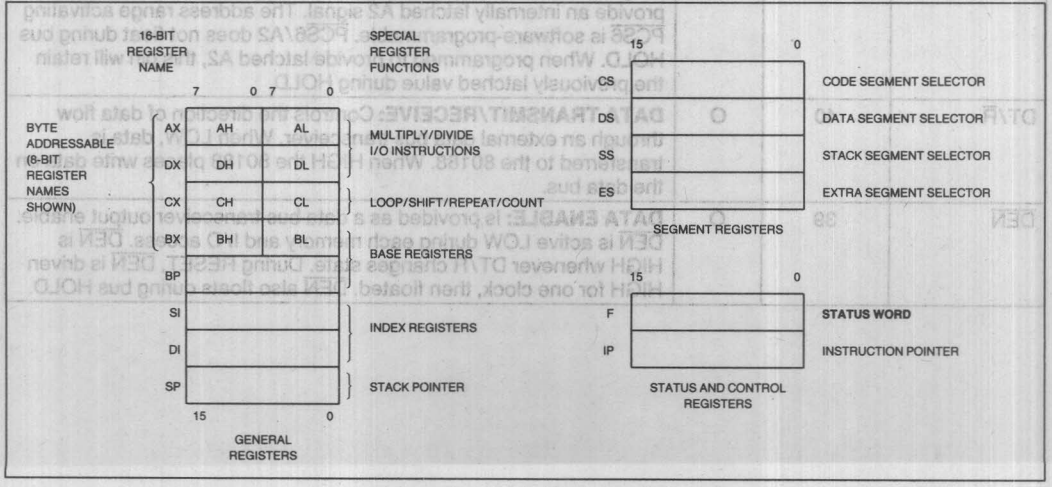


Figure 3a. 80188 Register Set

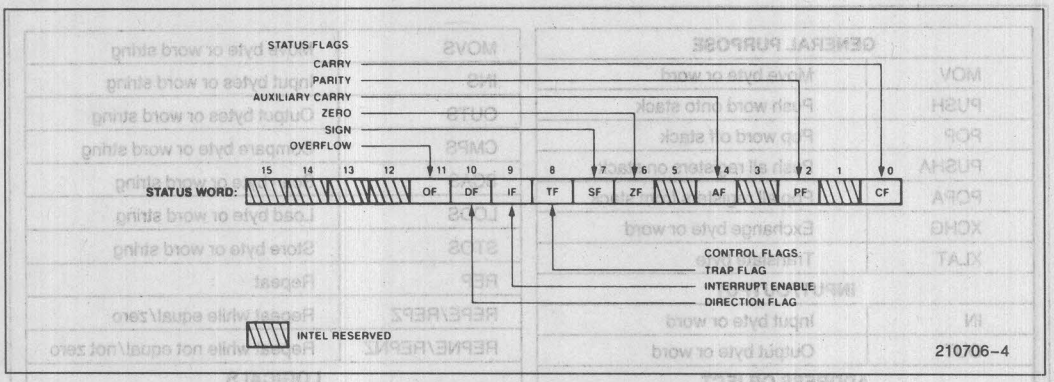


Figure 3b. Status Word Format

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag—Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-Enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80188 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment registers (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack
ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero
LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word
FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{TEST}}$ pin active
ESC	Escape to extension processor
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. 80188 Instruction Set

CONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal
JAE/JNB	Jump if above or equal/not below
JB/JNAE	Jump if below/not above nor equal
JBE/JNA	Jump if below or equal/not above
JC	Jump if carry
JE/JZ	Jump if equal/zero
JG/JNLE	Jump if greater/not less nor equal
JGE/JNL	Jump if greater or equal/not less
JL/JNGE	Jump if less/not greater nor equal
JLE/JNG	Jump if less or equal/not greater
JNC	Jump if not carry
JNE/JNZ	Jump if not equal/not zero
JNO	Jump if not overflow
JNP/JPO	Jump if not parity/parity odd
JNS	Jump if not sign
JO	Jump if overflow
JP/JPE	Jump if parity/parity even
JS	Jump if sign
UNCONDITIONAL TRANSFERS	
CALL	Call procedure
RET	Return from procedure
JMP	Jump
ITERATION CONTROLS	
LOOP	Loop
LOOPE/LOOPZ	Loop if equal/zero
LOOPNE/LOOPNZ	Loop if not equal/not zero
JCXZ	Jump if register CX = 0
INTERRUPTS	
INT	Interrupt
INTO	Interrupt if overflow
IRET	Interrupt return

Figure 4. 80188 Instruction Set (Continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

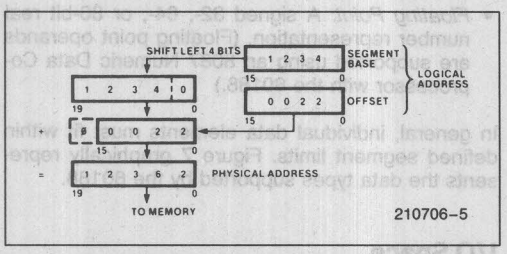


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

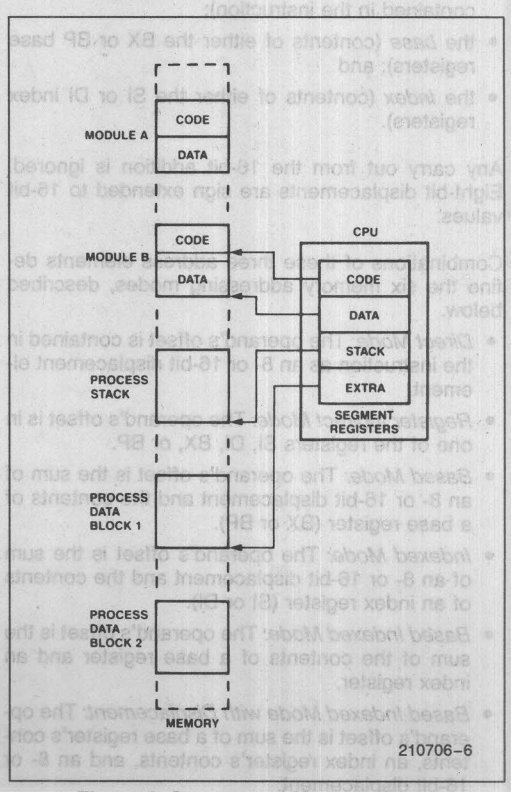


Figure 6. Segmented Memory Helps Structure Software

address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an index register.
- *Based Indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.
- *Floating Point:* A signed 32-, 64-, or 80-bit real number representation. (Floating point operands are supported using an 8087 Numeric Data Coprocessor with the 80188.)

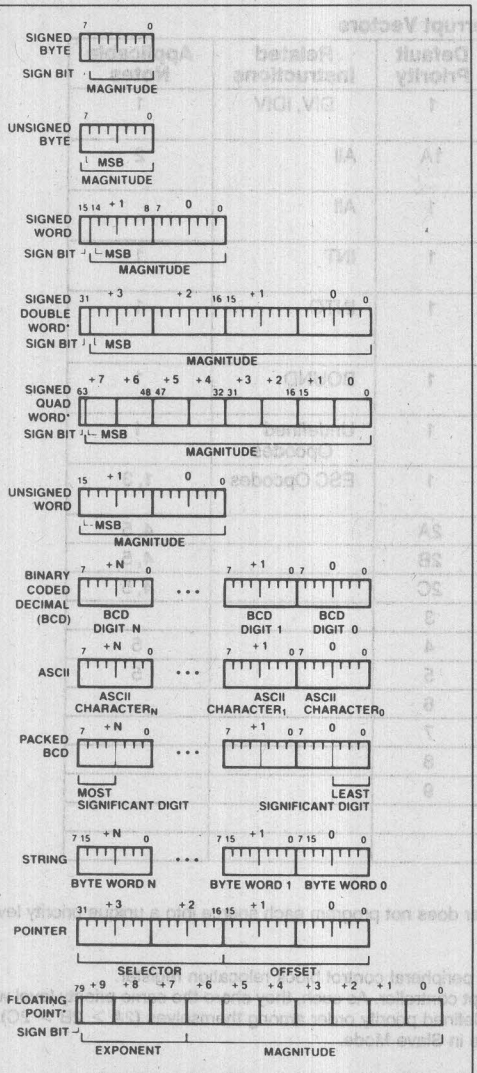
In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the 80188.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}–A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.



NOTE:
*Supported using an 8087 Numeric Data Coprocessor with the 80188.

Figure 7. 80188 Supported Data Types

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by executing an ESC instruction with the ESC trap bit set in the relocation register, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present. In all other cases, the return address from an exception will point at the instruction immediately following the instruction causing the exception.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31, some of which are used for instruction exceptions, are reserved. Table 4 shows the 80188 predefined types and default priority levels. For each interrupt, an 8-bit vector must be supplied to the 80188 which identifies the appropriate table entry. Exceptions supply the interrupt vector internally. In addition, internal peripherals and noncascaded external interrupts will generate their own vectors through the internal interrupt controller. INT instructions contain or imply the vector and allow access to all 256 interrupts. Maskable hardware initiated interrupts supply the 8-bit vector to the CPU during an interrupt acknowledge bus sequence. Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80188 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

Those pre-defined 80188 interrupts which cannot be masked by programming are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

SINGLE-STEP INTERRUPT (TYPE 1)

Generated after most instructions if the TF flag is set. Interrupts will not be generated after prefix instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)

An external interrupt source which cannot be masked.

Table 4. 80188 Interrupt Vectors

Interrupt Name	Vector Type	Vector Address	Default Priority	Related Instructions	Applicable Notes
Divide Error Exception	0	00H	1	DIV, IDIV	1
Single Step Interrupt	1	04H	1A	All	2
Non-Maskable Interrupt (NMI)	2	08H	1	All	
Breakpoint Interrupt	3	0CH	1	INT	1
INTO Detected Overflow Exception	4	10H	1	INTO	1
Array Bounds Exception	5	14H	1	BOUND	1
Unused Opcode Exception	6	18H	1	Undefined Opcodes	1
ESC Opcode Exception	7	1CH	1	ESC Opcodes	1, 3
Timer 0 Interrupt	8	20H	2A		4, 5
Timer 1 Interrupt	18	48H	2B		4, 5
Timer 2 Interrupt	19	4CH	2C		4, 5
Reserved	9	24H	3		
DMA 0 Interrupt	10	28H	4		5
DMA 1 Interrupt	11	2CH	5		5
INT0 Interrupt	12	30H	6		
INT1 Interrupt	13	34H	7		
INT2 Interrupt	14	38H	8		
INT3 Interrupt	15	3CH	9		
Reserved	16, 17	40H, 44H			
Reserved	20–31	50H . . . 7CH			

NOTES:
Default priorities for the interrupt sources are used only if the user does not program each source into a unique priority level.
1. Generated as a result of an instruction execution.
2. Performed in same manner as 8088.
3. An ESC opcode will cause a trap if the power bit is set in the peripheral control block relocation register.
4. All three timers constitute one source of request to the interrupt controller. As such, they share the same priority level with respect to other interrupt sources. However, the timers have a defined priority order among themselves (2A > 2B > 2C).
5. The vector type numbers for these sources are programmable in Slave Mode.

BREAKPOINT INTERRUPT (TYPE 3)

A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INTO DETECTED OVERFLOW EXCEPTION (TYPE 4)

Generated during an INTO instruction if the OF bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)

Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)

Generated if execution is attempted on undefined opcodes.

The vector types for these interrupts are shown in Table 4. Software enables these inputs by setting the Interrupt Flag bit (IF) in the Status Word. The interrupt controller is discussed in the peripheral section of this data sheet.

Further maskable interrupts are disabled while servicing an interrupt because the IF bit is reset as part of the response to an interrupt or exception. The saved Status Word will reflect the enable status of the processor prior to the interrupt. The interrupt flag will remain zero unless specifically set. The interrupt return instruction restores the Status Word, thereby restoring the original status of IF bit. If the interrupt return re-enables interrupts, and another interrupt is pending, the 80188 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Non-Maskable Interrupt Request (NMI)

A non-maskable interrupt (NMI) is also provided. This interrupt is serviced regardless of the state of the IF bit. A typical use of NMI would be to activate a power failure routine. The activation of this input causes an interrupt with an internally supplied vector value of 2. No external interrupt acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced.

Single-Step Interrupt

The 80188 has an internal interrupt that allows programs to execute one instruction at a time. It is called the single-step interrupt and is controlled by the single-step flag bit (TF) in the Status Word. Once this bit is set, an internal single-step interrupt will occur after the next instruction has been executed. The interrupt clears the TF bit and uses an internally supplied vector of 1. The IRET instruction is used to set the TF bit and transfer control to the next instruction to be single-stepped.

Instruction Pointer	0000(H)
Code Segment	FFFF(H)
Data Segment	0000(H)
Extra Segment	0000(H)
Stack Segment	0000(H)
Relocation Register	20FF(H)
UMCS	FFFB(H)

THE 80188 COMPARED TO THE 80186

The 80188 CPU is an 8-bit processor designed around the 80186 internal structure. Most internal functions of the 80188 are identical to the equivalent 80186 functions. The 80188 handles the external bus the same way the 80186 does with the distinction of handling only 8 bits at a time. Sixteen bit operands are fetched or written in two consecutive bus cycles. Both processors will appear identical to the software engineer, with the exception of execution time. The internal register structure is identical and all instructions have the same end result. The differences between the 80188 and the 80186 are outlined below. Internally, there are three differences between the 80188 and the 80186. All changes are related to the 8-bit bus interface.

- The queue length is 4 bytes in the 80188, whereas the 80186 queue contains 6 bytes, or three words. The queue was shortened to prevent overuse of the bus by the BIU when prefetching instructions. This was required because of the additional time necessary to fetch instructions 8 bits at a time.
- To further optimize the queue, the prefetching algorithm was changed. The 80188 BIU will fetch a new instruction to load into the queue each time there is a 1-byte hole (space available) in the queue. The 80186 waits until a 2-byte space is available.

- The internal execution time of the instruction is affected by the 8-bit interface. All 16-bit fetches and writes from/to memory take an additional four clock cycles. The CPU may also be limited by the speed of instruction fetches when a series of simple operations occur. When the more sophisticated instructions of the 80188 are being used, the queue has time to fill and the execution proceeds as fast as the execution unit will allow.

The 80188 and 80186 are completely software compatible by virtue of their identical execution units. Software that is system dependent may not be completely transferable, but software that is not system dependent will operate equally well on an 80188 or an 80186.

The hardware interface of the 80188 contains the major differences between the two CPUs. The pin assignments are nearly identical, however, with the following functional changes.

- A8–A15—These pins are only address outputs on the 80188. These address lines are latched internally and remain valid throughout a bus cycle in a manner similar to the 8085 upper address lines.
- $\overline{BHE}$ has no meaning on the 80188 and has been eliminated.

80188 Clock Generator

The 80188 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The oscillator circuit of the 80188 is designed to be used with a parallel resonant fundamental mode crystal. This is used as the time base for the 80188. The crystal frequency selected will be double the CPU clock frequency. Use of an LC or RC circuit is not recommended with this oscillator. If an external oscillator is used, it can be connected directly to input pin X1 in lieu of a crystal. The output of the oscillator is not directly available outside the 80188. The recommended crystal configuration is shown in Figure 8.

Intel recommends the following values for crystal selection parameters.

Temperature Range:	0 to 70°C
ESR (Equivalent Series Resistance):	30Ω max
C_0 (Shunt Capacitance of Crystal):	7.0 pf max
C_L (Load Capacitance):	20 pf ±2 pf
Drive Level:	1 mW max

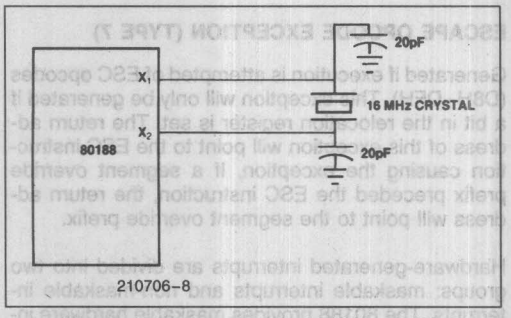


Figure 8. Recommended 8 MHz 80188 Crystal Configuration

Clock Generator

The 80188 clock generator provides the 50% duty cycle processor clock for the 80188. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the 80188. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The 80188 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3, and again in the middle of each T_W until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used for full synchronization of a rising ARDY signal. A high-to-low transition on ARDY may be used as an indication of the not ready condition but it must be performed synchronously to CLKOUT **either** in the middle of T_2, T_3, **or** T_W, or at the falling edge of T_3 or T_W.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3, and again at the end of each T_W until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated.

This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the 80188, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

RESET Logic

The 80188 provides both a $\overline{RES}$ input pin and a synchronized RESET output pin for use with other system components. The $\overline{RES}$ input pin on the 80188 is provided with hysteresis in order to facilitate power-on Reset generation via an RC network. RESET output is guaranteed to remain active for at least five clocks given a $\overline{RES}$ input of at least six clocks. RESET may be delayed up to approximately two and one-half clocks behind $\overline{RES}$.

Multiple 80188 processors may be synchronized through the $\overline{RES}$ input pin, since this input resets both the processor and divide-by-two internal counter in the clock generator. In order to ensure that the divide-by-two counters all begin counting at the same time, the active going edge of $\overline{RES}$ must satisfy a 25 ns setup time before the falling edge of the 80188 clock input. In addition, in order to ensure that all CPUs begin executing in the same clock cycle, the reset must satisfy a 25 ns setup time before the rising edge of the CLKOUT signal of all the processors.

LOCAL BUS CONTROLLER

The 80188 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides outputs that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The 80188 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory or I/O to the 80188 or to strobe data from the 80188 to memory or I/O. The ALE line provides a strobe to latch the address when it is valid. The 80188 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The 80188 generates two control signals for external transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

Table 6. Transceiver Control Signals Description

Pin Name	Function
$\overline{DEN}$ (Data Enable)	Enables the output drivers of the transceivers. It is active LOW during memory, I/O, or INTA cycles.
DT/$\overline{R}$ (Data Transmit/ Receive)	Determines the direction of travel through the transceivers. A HIGH level directs data away from the processor during write operations, while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The 80188 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The 80188 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. External circuitry must arbitrate which external device will gain control of the bus when there is more than one alternate local bus master. When the 80188 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$–$\overline{S2}$, $\overline{LOCK}$, AD0–AD7, A8–A19, $\overline{S7}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The 80188 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is the highest-priority activity request which the processor may receive: higher than instruction fetching or internal DMA cycles. However, if a DMA cycle is in progress, the 80188 will complete the transfer before relinquishing the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency time can be as great as 4 bus cycles. This will occur if a DMA word transfer operation is taking place from an odd address to an odd address. This is a total of 16 clocks or more, if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

Local Bus Controller and Reset

During RESET the local bus controller will perform the following actions:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float.

NOTE:
$\overline{RD}$ is also provided with an internal pull-up device to prevent the processor from inadvertently entering Queue Status Mode during RESET.

- Drive $\overline{S0}$–$\overline{S2}$ to the inactive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Three-state AD0–7, A8–19, S7, DT/$\overline{R}$.
- Drive ALE LOW (ALE is never floated).
- Drive HLDA LOW.

INTERNAL PERIPHERAL INTERFACE

All the 80188 integrated peripherals are controlled by 16-bit registers contained within an internal 256-byte control block. The control block may be mapped into either memory or I/O space. Internal logic will recognize control block addresses and respond to bus cycles. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{7-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80188 CPU at any time

The control block base address is programmed by a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. Note that mapping the control register block into an address range corresponding to a chip-select range is not recommended (the chip select circuitry is discussed later in this data sheet. In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space. If the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

Whenever mapping the 188 peripheral control block to another location, the programming of the relocation register should be done with a byte write (i.e. OUT DX,AL). Any access to the control block is done 16 bits at a time. Thus, internally, the relocation register will get written with 16 bits of the AX register while externally, the BIU will run only one 8-bit bus cycle. If a word instruction is used (i.e. OUT DX,AX), the relocation register will be written on the first bus cycle. The Bus Interface Unit (BIU) will then run a second bus cycle which is unnecessary. The address of the second bus cycle will no longer be within the control block (i.e. the control block was moved on the first cycle), and therefore, will require the generation of an external ready signal to complete the cycle. For this reason we recommend byte operations to the relocation register. Byte instructions may also be used for the other registers in the control block and will eliminate half of the bus cycles required if a word operation had been specified. Byte operations are only valid on even addresses though, and are undefined on odd addresses.

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into Slave Mode, and cause the CPU to interrupt upon encountering ESC instructions. At RESET, the relocation register is set to 20FFH which maps the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

CHIP-SELECT/READY GENERATION LOGIC

The 80188 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

Memory Chip Selects

The 80188 provides 6 memory chip select outputs for 3 address areas: upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address

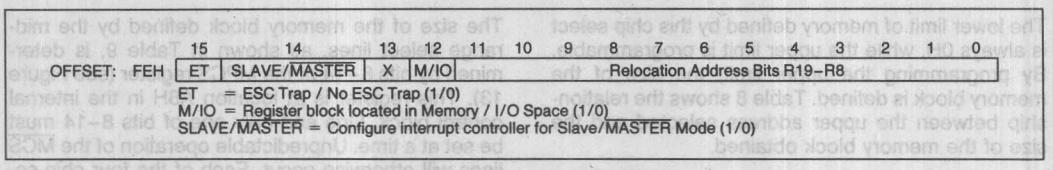


Figure 9. Relocation Register

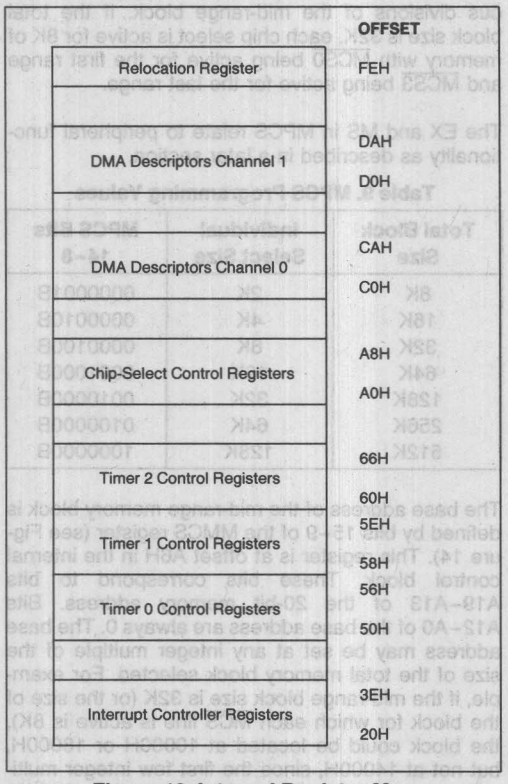


Figure 10. Internal Register Map

of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes.

Upper Memory $\overline{CS}$

The 80188 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the 80188 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0 = R1 = R2 = 0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

The internal generation of any 20-bit address whose upper 16 bits are equal to or greater than the UMCS value (with bits 0–5 as "0") asserts $\overline{UCS}$. UMCS bits R2–R0 specify the ready mode for the area of memory defined by the chip select register, as explained later.

Lower Memory $\overline{CS}$

The 80188 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0 = R1 = R2 = 0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12) at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After RESET, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will assert $\overline{LCS}$. LMCS register bits R2–R0 specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The 80188 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located within the 80188 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. If the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as described in a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14–8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After RESET, the contents of both of these registers are undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

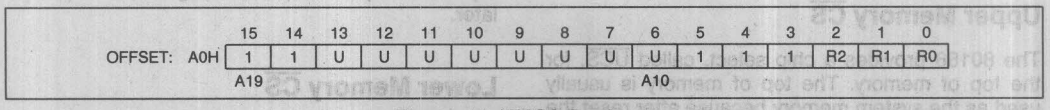


Figure 11. UMCS Register

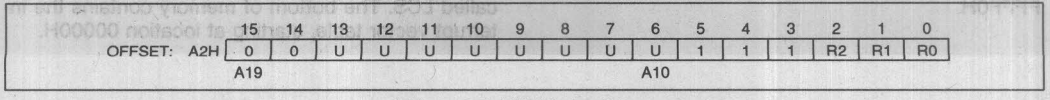


Figure 12. LMCS Register

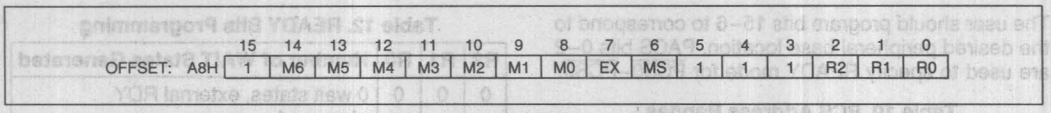


Figure 13. MPCS Register

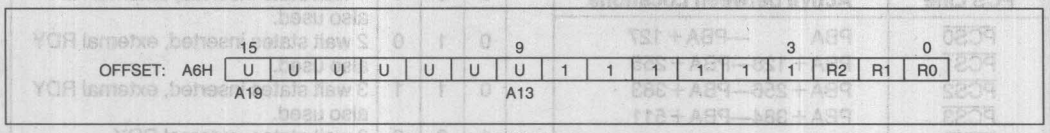


Figure 14. MMCS Register

MMCS bits R2–R0 specify READY mode of operation for all four mid-range chip selects.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

Peripheral Chip Selects

The 80188 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a programmable base address. The base address may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the 80188. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1 and A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0 and A1 pins used for selecting internal registers of 8-bit peripheral chips.

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). The register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

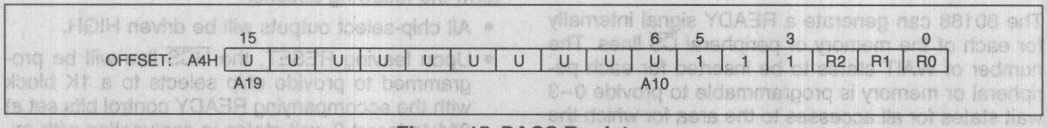


Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

$\overline{PCS}$ Line	Active between Locations
$\overline{PCS0}$	PBA —PBA + 127
$\overline{PCS1}$	PBA + 128—PBA + 255
$\overline{PCS2}$	PBA + 256—PBA + 383
$\overline{PCS3}$	PBA + 384—PBA + 511
$\overline{PCS4}$	PBA + 512—PBA + 639
$\overline{PCS5}$	PBA + 640—PBA + 767
$\overline{PCS6}$	PBA + 768—PBA + 895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 13). The register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After RESET, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space.
	0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided.
	1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 specify the READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The 80188 can generate a READY signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the 80188 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the 80188. The interpretation of the READY bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal READY generator operates in parallel with external READY, not in series if the external READY is used (R2 = 0). For example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon RESET, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to insert 3 wait states in conjunction with external READY (i.e., UMCS resets to FFFBH).
- No other chip select or READY control registers have any predefined values after RESET. They will not become active until the CPU accesses their control registers. Both the PACS and MPCS registers must be accessed before the $\overline{PCS}$ lines will become active.

DMA Channels

The 80188 DMA controller provides two independent DMA channels. Data transfers can occur between memory and I/O spaces (e.g., Memory to I/O) or within the same space (e.g., Memory to Memory or I/O to I/O). Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer. Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data. This provides a data transfer rate of one MByte/sec at 8 MHz.

DMA Operation

Each channel has six registers in the control block which define each channel's operation. The control registers consist of a 20-bit Source pointer (2 words), a 20-bit Destination pointer (2 words), a 16-bit Transfer Count Register, and a 16-bit Control Word.

The format of the DMA Control Blocks is shown in Table 13. The Transfer Count Register (TC) specifies the number of DMA transfers to be performed. Up to 64K byte transfers can be performed with automatic termination. The Control Word defines the channel's operation (see Figure 17). All registers may be modified or altered during any DMA activity. Any changes made to these registers will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

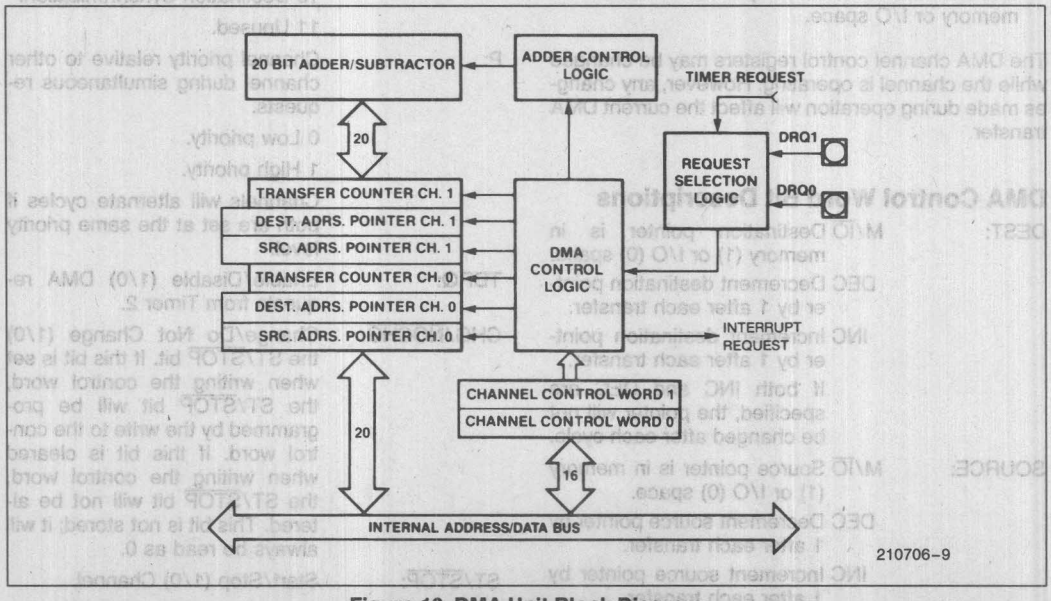


Figure 16. DMA Unit Block Diagram

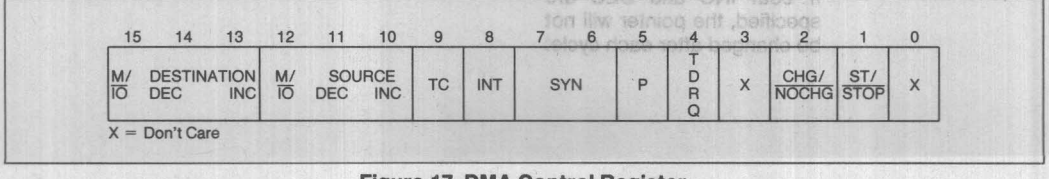


Figure 17. DMA Control Register

DMA Channel Control Word Register

Each DMA Channel Control Word determines the mode of operation for the particular 80188 DMA channel. This register specifies:

- the mode of synchronization;
- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

DEST: M/$\overline{IO}$ Destination pointer is in memory (1) or I/O (0) space.

DEC Decrement destination pointer by 1 after each transfer.

INC Increment destination pointer by 1 after each transfer.

If both INC and DEC are specified, the pointer will not be changed after each cycle.

SOURCE: M/$\overline{IO}$ Source pointer is in memory (1) or I/O (0) space.

DEC Decrement source pointer by 1 after each transfer.

INC Increment source pointer by 1 after each transfer.

If both INC and DEC are specified, the pointer will not be changed after each cycle.

TC: If set, DMA will terminate when the contents of the transfer count register reach zero. The ST/$\overline{STOP}$ bit will also be reset at this point. If cleared, the DMA controller will decrement the transfer count register for each DMA cycle, but DMA transfers will not stop when the transfer count register reaches zero.

INT: Enable interrupts to CPU upon transfer count termination.

SYN: 00 No synchronization.

NOTE:

When unsynchronized transfers are specified, the TC bit will be ignored and the ST bit will be cleared upon the transfer count reaching zero, stopping the channel.

01 Source Synchronization.

10 Destination Synchronization.

11 Unused.

P: Channel priority relative to other channel during simultaneous requests.

0 Low priority.

1 High priority.

Channels will alternate cycles if both are set at the same priority level.

TDRQ: Enable/Disable (1/0) DMA requests from Timer 2.

CHG/$\overline{NOCHG}$: Change/Do Not Change (1/0) the ST/$\overline{STOP}$ bit. If this bit is set when writing the control word, the ST/$\overline{STOP}$ bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/$\overline{STOP}$ bit will not be altered. This bit is not stored; it will always be read as 0.

ST/$\overline{STOP}$: Start/Stop (1/0) Channel.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18). These pointers may be individually incremented or decremented after each transfer. Each pointer may point into either memory or I/O space. Since the DMA channels can perform transfers to or from odd addresses, there is no restriction on values for the pointer registers.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). The register is decremented after every DMA cycle, regardless of the state of the TC bit in the DMA Control Register. If the TC bit in the DMA control word is set or if unsynchronized transfers are programmed, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). When destination synchronized transfers are performed, data will not be fetched from the source address until the destination device signals that it is ready to receive it. Also, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another destination synchronized DMA cycle will begin after two processor clocks. This allows the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. Table 14 shows the maximum DMA transfer rates.

Table 14. Maximum DMA Transfer Rates @ CLKOUT = 8 MHz

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	1.0 MBytes/sec	1.0 MBytes/sec
Source Synch	1.0 MBytes/sec	1.0 MBytes/sec
Destination Synch	0.67 MBytes/sec	0.80 MBytes/sec

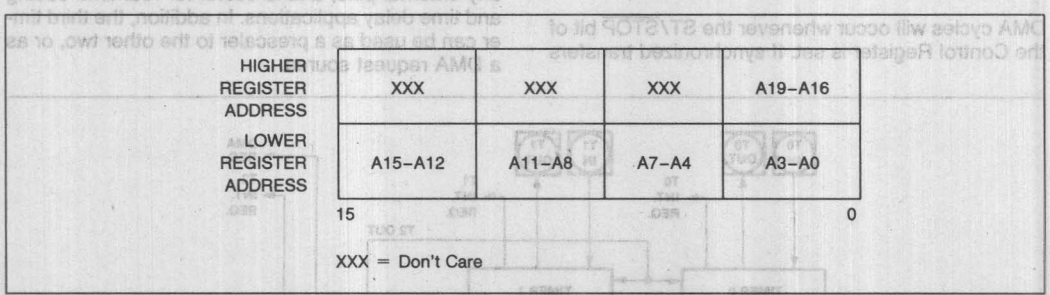


Figure 18. DMA Pointer Register Format

DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed to give one channel priority over the other, or they may be programmed to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses or word accesses to odd memory locations; also, an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/$\overline{\text{STOP}}$ bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also be generated. Therefore, the source and destination transfer pointers, and the transfer count register (if used) must be programmed before the ST/$\overline{\text{STOP}}$ bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/$\overline{\text{NOCHG}}$ bit is cleared when the control register is written, the ST/$\overline{\text{STOP}}$ bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the DMA channels will perform the following actions:

- The ST/$\overline{\text{STOP}}$ bit for each channel will be reset to STOP.
- Any transfer in progress is aborted.

TIMERS

The 80188 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, the third timer can be used as a prescaler to the other two, or as a DMA request source.

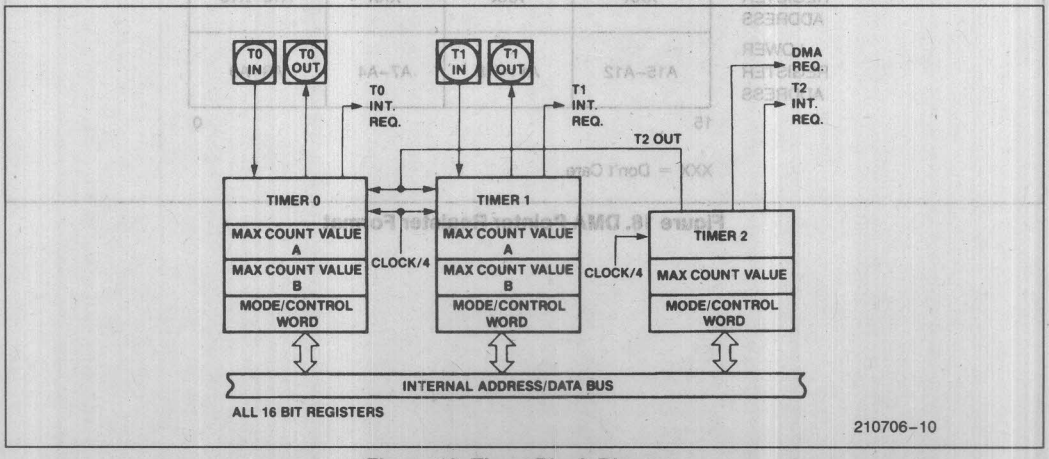


Figure 19. Timer Block Diagram

Timer Operation

The timers are controlled by 11 16-bit registers in the peripheral control block. The configuration of these registers is shown in Table 15. The count register contains the current value of the timer. It can be read or written at any time independent of whether the timer is running or not. The value of this register will be incremented for each timer event. Each of the timers is equipped with a MAX COUNT register, which defines the maximum count the timer will reach. After reaching the MAX COUNT register value, the timer count value will reset to zero during that same clock, i.e., the maximum count value is never stored in the count register itself. Timers 0 and 1 are, in addition, equipped with a second MAX COUNT register, which enables the timers to alternate their count between two different MAX COUNT values. If a single MAX COUNT register is used, the timer output pin will switch LOW for a single clock, 2 clocks after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate (2 MHz for an 8 MHz CPU clock). Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input.

Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.
- Timers 0 and 1 can select between internal and external clocks, alternate between MAX COUNT registers and be set to retrigger on external events.
- The timers may be programmed to cause an interrupt on terminal count.

These options are selectable via the timer mode/control word.

Timer Mode/Control Register

The mode/control register (see Figure 20) allows the user to program the specific mode of operation or check the current programmed status for any of the three integrated timers.

Table 15. Timer Control Block Format

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

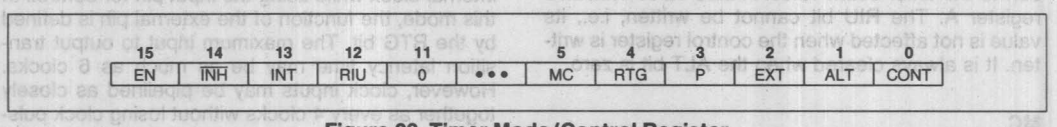


Figure 20. Timer Mode/Control Register

mode/control word, then the state of the EN bit will be modified by the write. If $\overline{INH}$ is a zero during the write, the EN bit will be unaffected by the operation. This bit is not stored; it will always be a 0 on a read.

INT

When set, the INT bit enables interrupts from the timer, which will be generated on every terminal count. If the timer is configured in dual MAX COUNT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller.)

RIU

The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

MC

The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts. Programmer intervention is required to clear this bit.

clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

P

The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

EXT

The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80188 clock. If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

ALT

The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of

the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT

Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT = 1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The contents of this register may be read or written by the processor at any time. If the register is written while the timer is counting, the new value will take effect in the current count cycle.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached. A timer resets when the timer count register equals the max count value being used. If the timer count register or the max count register is changed so that the max count is less than the timer count, the timer does not immediately reset. Instead, the timer counts up to 0FFFFH, "wraps around" to zero, counts up to the max count value, and then resets.

Timers and Reset

Upon RESET, the Timers will perform the following actions:

- All EN (Enable) bits are reset preventing timer counting.
- For Timers 0 and 1, the RIU bits are reset to zero and the ALT bits are set to one. This results in the Timer Out pins going HIGH.

INTERRUPT CONTROLLER

The 80188 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80188 interrupt controller has its own control register that sets the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service routines for lower priority interrupts may be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The 80188 has a special Slave Mode in which the internal interrupt controller acts as a slave to an external master. The controller is programmed into this mode by setting bit 14 in the peripheral control block relocation register. (See Slave Mode section.)

MASTER MODE OPERATION

Interrupt Controller External Interface

Five pins are provided for external interrupt sources. One of these pins is NMI, the non-maskable interrupt. NMI is generally used for unusual events such as power-fail interrupts. The other four pins may be configured in any of the following ways:

- As four interrupt input lines with internally generated interrupt vectors.
- As an interrupt line and interrupt acknowledge line pair (Cascade Mode) with externally generated interrupt vectors plus two interrupt input lines with internally generated vectors.
- As two pairs of interrupt/interrupt acknowledge lines (Cascade Mode) with externally generated interrupt vectors.

External sources in the Cascade Mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80188 on the second cycle. The capability to interface to external 8259A programmable interrupt controllers is provided when the inputs are configured in Cascade Mode.

Interrupt Controller Modes of Operation

The basic modes of operation of the interrupt controller in Master Mode are similar to the 8259A. The interrupt controller responds identically to internal interrupts in all three modes: the difference is only in the interpretation of function of the four external interrupt pins. The interrupt controller is set into one of these three modes by programming the correct bits in the INT0 and INT1 control registers. The modes of interrupt controller operation are as follows:

FULLY NESTED MODE

When in the fully nested mode four pins are used as direct interrupt requests as in Figure 22. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in-service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the in-service bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled, yet be suspended only by interrupts of higher priority than the in-service interrupt.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is executed at the end of the service routine just before the return from interrupt instruction. If the fully nested structure has been upheld, the next highest-priority source with its IS bit set is then serviced.

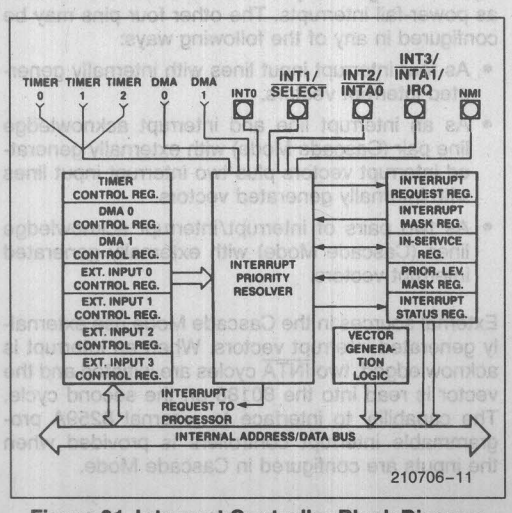


Figure 21. Interrupt Controller Block Diagram

CASCADE MODE

The 80188 has four interrupt pins and two of them have dual functions. In the fully nested mode the four pins are used as direct interrupt inputs and the corresponding vectors are generated internally. In the Cascade Mode, the four pins are configured into interrupt input-dedicated acknowledge signal pairs. The interconnection is shown in Figure 23. INT0 is an interrupt input interfaced to an 8259A, while INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the Cascade Mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary Cascade Mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 8259As. Three levels of priority are created, requiring priority resolution in the 80188 interrupt controller, the master 8259As, and the slave 8259As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

SPECIAL FULLY NESTED MODE

This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 8259A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80188 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80188 controller until the 80188 in-service bit is reset. In Special Fully Nested Mode, the 80188 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80188 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the IS register in the external master 8259A is required to determine if there is more than one bit set. If so, the IS bit in the 80188 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (Figure 32). Bit 15 in the poll word indicates to the processor that an interrupt of high enough priority is requesting service. Bits 0–4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80188 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

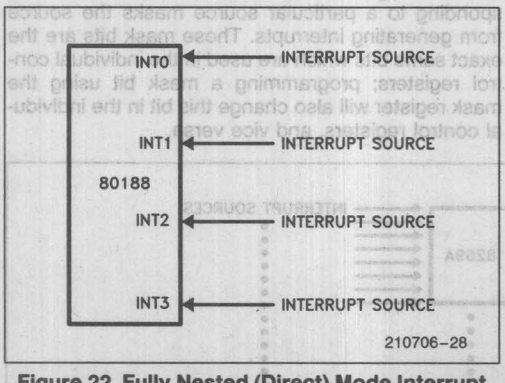


Figure 22. Fully Nested (Direct) Mode Interrupt Controller Connections

Master Mode Features

PROGRAMMABLE PRIORITY

The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority). All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, other interrupt requests can be serviced.

END-OF-INTERRUPT COMMAND

The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

TRIGGER MODE

The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the 80188 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to re-enable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

INTERRUPT VECTORING

The 80188 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Modes. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 24. It contains 15 registers. All registers can both be read or written unless specified otherwise.

IN-SERVICE REGISTER

This register can be read from or written into. The format is shown in Figure 25. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command.

INTERRUPT REQUEST REGISTER

The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 25. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits are set when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Writes to to the interrupt request register will affect the D0 and D1 interrupt request bits. Setting either bit will cause the corresponding interrupt request while clearing either bit will remove the corresponding interrupt request. All other bits in the register are read-only.

MASK REGISTER

This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 25. A one in a bit position corresponding to a particular source masks the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

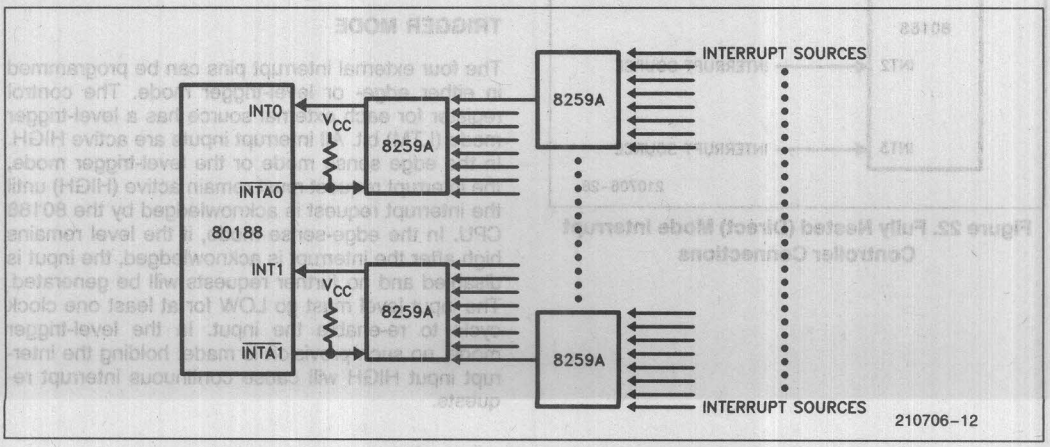


Figure 23. Cascade and Special Fully Nested Mode Interrupt Controller Connections

	OFFSET
INT3 CONTROL REGISTER	3EH
INT2 CONTROL REGISTER	3CH
INT1 CONTROL REGISTER	3AH
INT0 CONTROL REGISTER	38H
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	34H
TIMER CONTROL REGISTER	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY MASK REGISTER	2AH
MASK REGISTER	28H
POLL STATUS REGISTER	26H
POLL REGISTER	24H
EOI REGISTER	22H

Figure 24. Interrupt Controller Registers (Master Mode)

PRIORITY MASK REGISTER

This register masks all interrupts below a particular interrupt priority level. The format of this register is shown in Figure 26. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so no interrupts are masked due to priority number.

INTERRUPT STATUS REGISTER

This register contains general interrupt controller status information. The format of this register is shown in Figure 27. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. This bit allows prompt service of all non-maskable interrupts. This bit may also be set by the programmer.

IRTx: These three bits represent the individual timer interrupt request bits. These bits differentiate between timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt requests. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

15	14	•	•	•	10	9	8	7	6	5	4	3	2	1	0
0	0	•	•	•	0	0	0	I3	I2	I1	I0	D1	D0	0	TMR

Figure 25. In-Service, Interrupt Request, and Mask Register Formats

15	14	•	•	•	•	•	•	•	•	•	•	3	2	1	0
0	0	•	•	•	•	•	•	•	•	•	•	0	PRM2	PRM1	PRM0

Figure 26. Priority Mask Register Format

15	14	•	•	•	•	•	•	7	6	5	4	3	2	1	0
DHLT	0	•	•	•	•	•	•	0	0	0	0	0	IRT2	IRT1	IRT0

Figure 27. Interrupt Status Register Format (non-RMX Mode)

TIMER, DMA 0, 1; CONTROL REGISTERS

These registers are the control words for all the internal interrupt sources. The format for these registers is shown in Figure 28. The three bit positions PR0, PR1, and PR2 represent the programmable priority level of the interrupt source. The MSK bit inhibits interrupt requests from the interrupt source. The MSK bits in the individual control registers are the exact same bits as are in the Mask Register; modifying them in the individual control registers will also modify them in the Mask Register, and vice versa.

INT0-INT3 CONTROL REGISTERS

These registers are the control words for the four external input pins. Figure 29 shows the format of the INT0 and INT1 Control registers; Figure 30 shows the format of the INT2 and INT3 Control registers. In Cascade Mode or Special Fully Nested Mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest priority = 000, lowest priority = 111.

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this level is preceded by an inactive-to-active transition on the line. In both cases, the level must remain active until the interrupt is acknowledged.

MSK: Mask bit, 1 = mask; 0 = non-mask.

C: Cascade mode bit, 1 = cascade; 0 = direct.

SFNM: Special Fully Nested Mode bit, 1 = SFNM.

EOI REGISTER

The end of the interrupt register is a command register which can only be written into. The format of this register is shown in Figure 31. It initiates an EOI command when written to by the 80188 CPU.

The bits in the EOI register are encoded as follows:

S_x: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10.

NOTE:
To reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

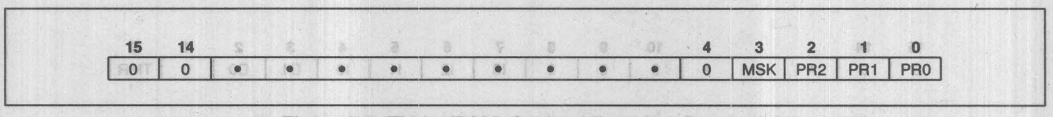


Figure 28. Timer/DMA Control Register Formats

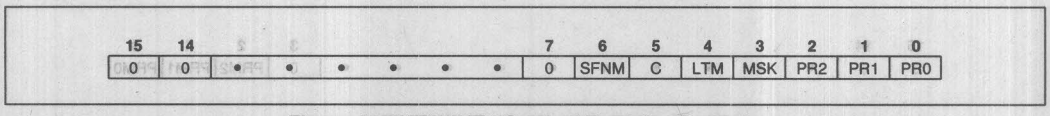


Figure 29. INT0/INT1 Control Register Formats

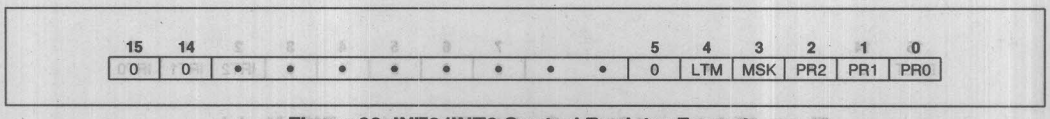


Figure 30. INT2/INT3 Control Register Formats

POLL AND POLL STATUS REGISTERS

These registers contain polling information. The format of these registers is shown in Figure 32. They can only be read. Reading the Poll register constitutes a software poll. This will set the IS bit of the highest priority pending interrupt. Reading the poll status register will not set the IS bit of the highest priority pending interrupt; only the status of pending interrupts will be provided.

Encoding of the Poll and Poll Status register bits are as follows:

S_x: Encoded information that indicates the vector type of the highest priority interrupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

SLAVE MODE OPERATION

When Slave Mode is used, the internal 80188 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80188 resources will be monitored by the internal interrupt controller, while the external controller functions as the system master interrupt controller. Upon reset, the 80188 will be in Master Mode. To provide for slave mode operation bit 14 of the relocation register should be set.

Because of pin limitations caused by the need to interface to an external 8259A master, the internal interrupt controller will no longer accept external inputs. There are however, enough 80188 interrupt controller inputs (internally) to dedicate one to each timer. In this mode, each timer interrupt source has its own mask bit, IS bit, and control word.

In Slave Mode each peripheral must be assigned a unique priority to ensure proper interrupt controller operation. Therefore, it is the programmer's responsibility to assign correct priorities and initialize interrupt control regisers before enable interrupts.

Slave Mode External Interface

The configuration of the 80188 with respect to an external 8259A master is shown in Figure 33. The INT0 (pin 45) input is used as the 80188 CPU interrupt input. IRQ (pin 41) functions as an output to send the 80188 slave-interrupt-request to one of the 8 master-PIC-inputs.

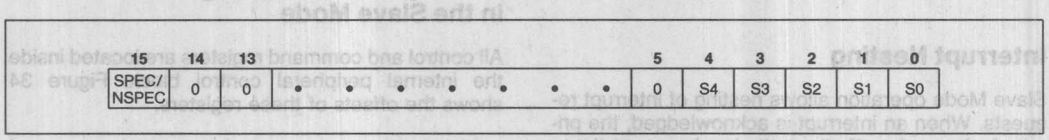


Figure 31. EOI Register Format

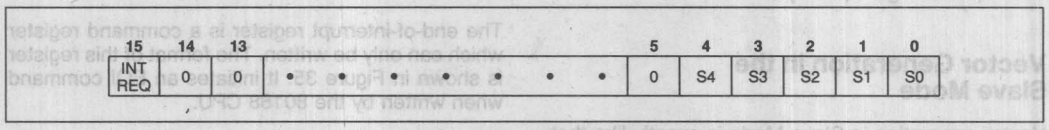


Figure 32. Poll and Poll Status Register Format

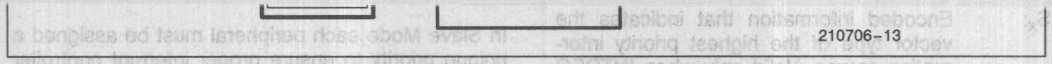


Figure 33. Slave Mode Interrupt Controller Connections

Correct master-slave interface requires decoding of the slave addresses (CAS0–2). Slave 8259As do this internally. Because of pin limitations, the 80188 slave address will have to be decoded externally. $\overline{\text{SELECT}}$ (pin 44) is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{\text{INTA0}}$ (pin 42) is used as an acknowledge output, suitable to drive the $\overline{\text{INTA}}$ input of an 8259A.

Interrupt Nesting

Slave Mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the Slave Mode

Vector generation in Slave Mode is exactly like that of an 8259A or 82C59A slave. The interrupt controller generates an 8-bit vector type number which the CPU multiplies by four to use as an address into the vector table. The five most significant bits of this type number are user-programmable while the three least significant bits are defined according to Figure 34. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In Slave Mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the Slave Mode

All control and command registers are located inside the internal peripheral control block. Figure 34 shows the offsets of these registers.

END-OF-INTERRUPT REGISTER

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 35. It initiates an EOI command when written by the 80188 CPU.

The bits in the EOI register are encoded as follows:

VT_X: Three least-significant vector type bits corresponding to the source for which the IS bit is to be reset. Figure 34 indicates these bits.

IN-SERVICE REGISTER

This register can be read from or written into. It contains the in-service bit for each of the internal interrupt sources. The format for this register is shown in Figure 36. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

INTERRUPT REQUEST REGISTER

This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 36. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request. As in Master Mode, D0 and D1 are read/write, all other bits are read only.

MASK REGISTER

This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 36. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

CONTROL REGISTERS

These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 37. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source.

msk: mask bit for the priority level indicated by pr_x bits.

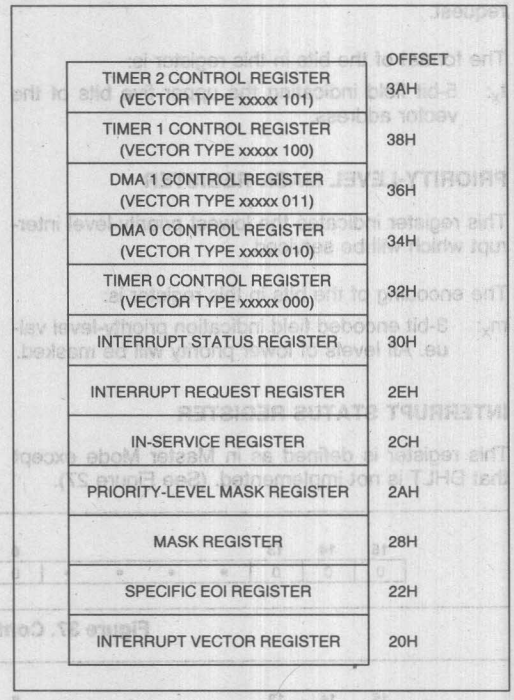


Figure 34. Interrupt Controller Registers (Slave Mode)

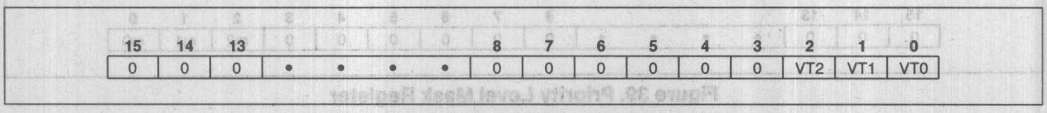


Figure 35. Specific EOI Register Format

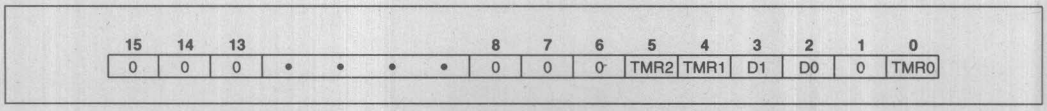


Figure 36. In-Service, Interrupt Request, and Mask Register Format

INTERRUPT VECTOR REGISTER

This register provides the upper five bits of the interrupt vector address. The format of this register is shown in Figure 38. The interrupt controller itself provides the lower three bits of the interrupt vector as determined by the priority level of the interrupt request.

The format of the bits in this register is:

t_x: 5-bit field indicating the upper five bits of the vector address.

PRIORITY-LEVEL MASK REGISTER

This register indicates the lowest priority-level interrupt which will be serviced.

The encoding of the bits in this register is:

m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

INTERRUPT STATUS REGISTER

This register is defined as in Master Mode except that DHLT is not implemented. (See Figure 27).

Interrupt Controller and Reset

Upon RESET, the interrupt controller will perform the following actions:

- All SFNM bits reset to 0, implying Fully Nested Mode.
- All PR bits in the various control registers set to 1. This places all sources at lowest priority (level 111).
- All LTM bits reset to 0, resulting in edge-sense mode.
- All Interrupt Service bits reset to 0.
- All Interrupt Request bits reset to 0.
- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-Cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to Master Mode.

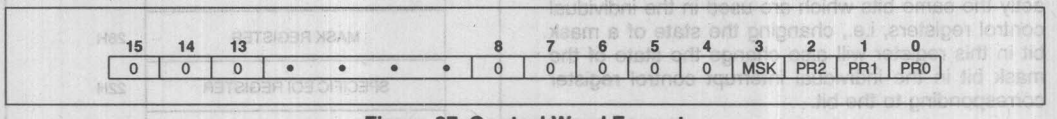


Figure 37. Control Word Format

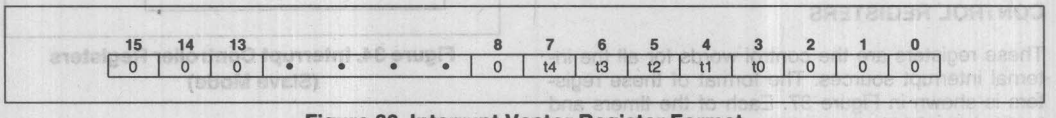


Figure 38. Interrupt Vector Register Format

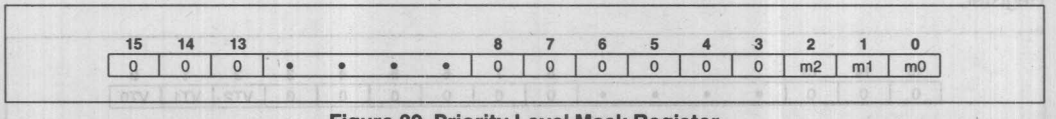


Figure 39. Priority Level Mask Register

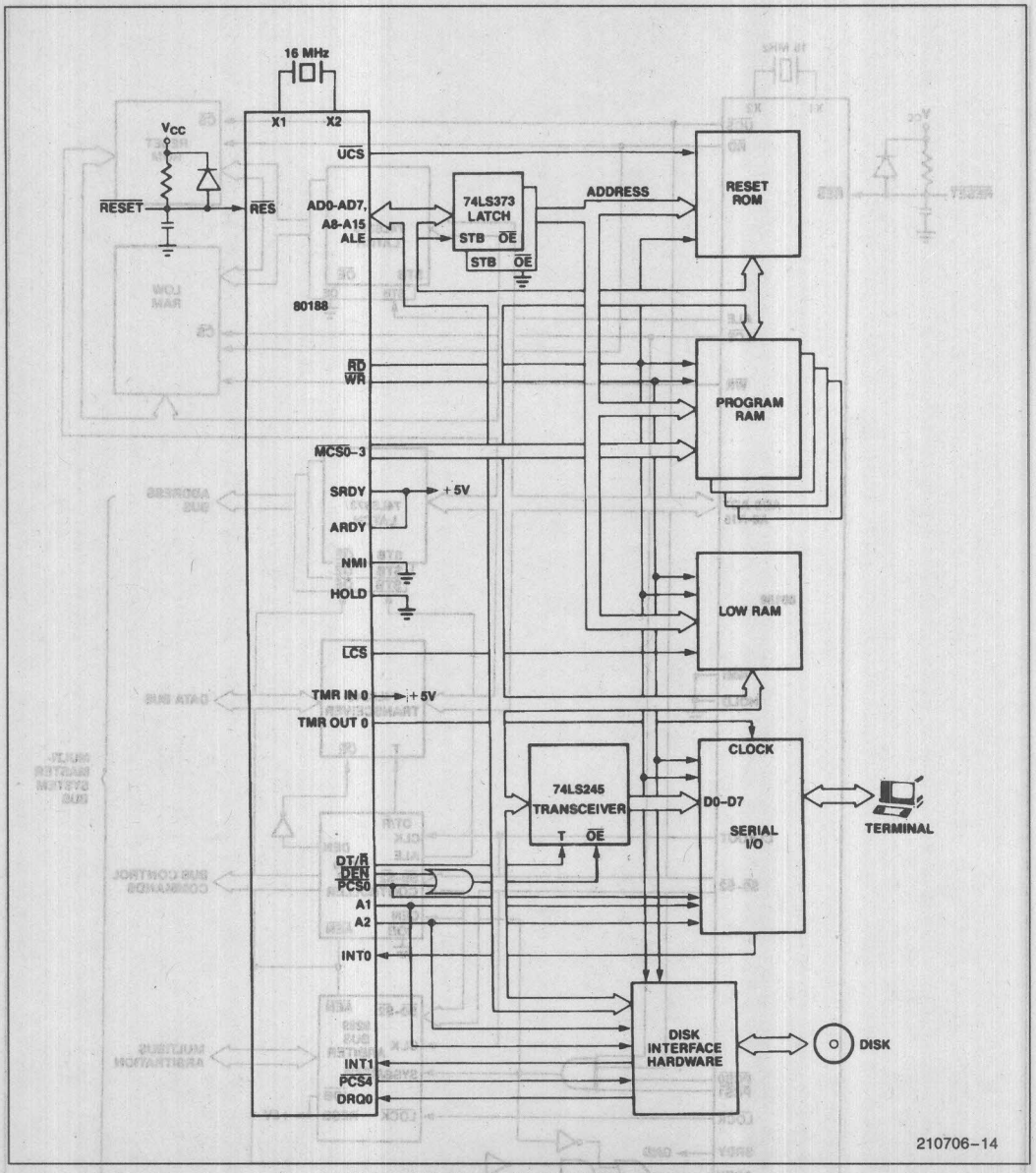


Figure 40. Typical 80188 Computer

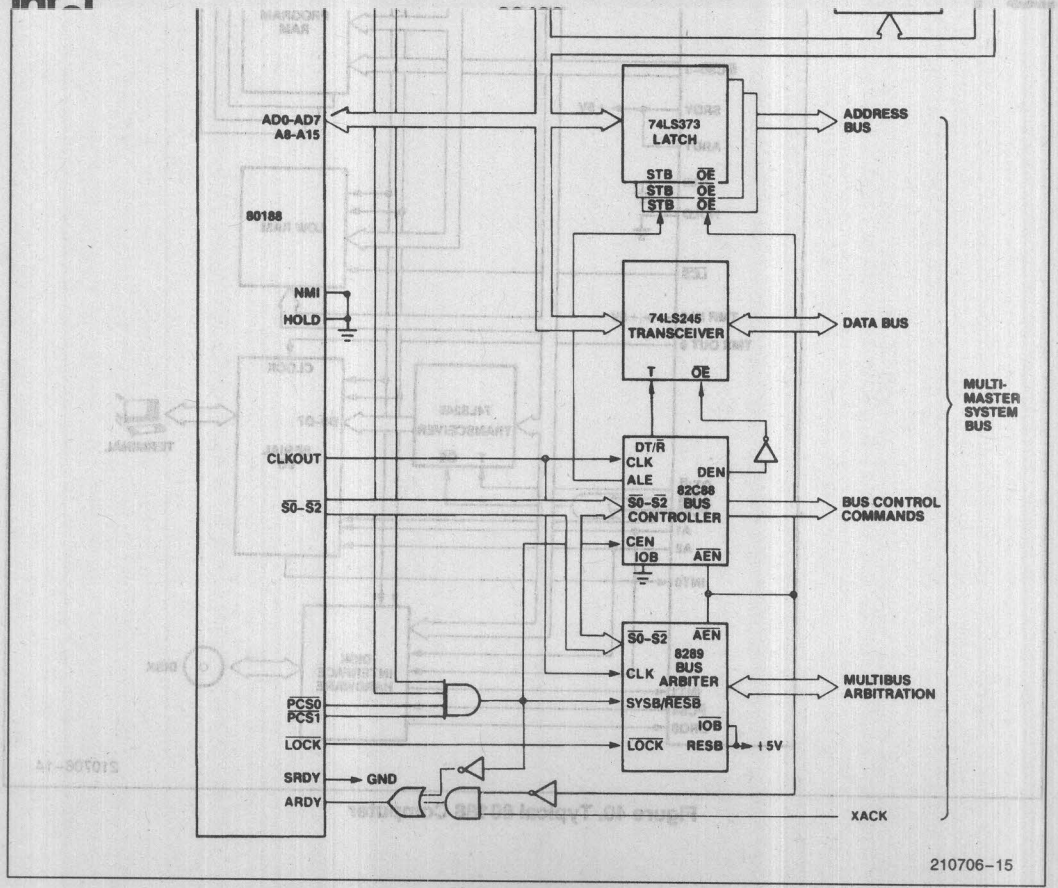


Figure 41. Typical 80188 Multi-Master Bus Interface

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ....0°C to +70°C
Storage Temperature .....−65°C to +150°C
Voltage on any Pin with Respect to Ground.....−1.0V to +7V
Power Dissipation .....3 Watt

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

D.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = 5V ±10%)

Applicable to 80188 (8 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.5	+0.8	V	
V_{IH}	Input High Voltage (All except X1 and $\overline{RES}$)	2.0	V_{CC} + 0.5	V	
V_{IH1}	Input High Voltage ($\overline{RES}$)	3.0	V_{CC} + 0.5	V	
V_{CLI}	X1 Input Low Voltage	−0.5	0.6	V	
V_{CHI}	X1 Input High Voltage	3.9	V_{CC} + 1.0	V	
V_{OL}	Output Low Voltage		0.45	V	I_a = 2.5 mA for $\overline{S0}$–$\overline{S2}$ I_a = 2.0 mA for all other outputs
V_{OH}	Output High Voltage	2.4		V	I_{oa} = −400 μA
I_{CC}	Power Supply Current		600*	mA	T_A = −40°C
			550	mA	T_A = 0°C
			415	mA	T_A = +70°C
I_{LI}	Input Leakage Current		±10	μA	0V < V_{IN} < V_{CC}
I_{LO}	Output Leakage Current		±10	μA	0.45V < V_{OUT} < V_{CC}
V_{CLO}	Clock Output Low		0.6	V	I_a = 4.0 mA
V_{CHO}	Clock Output High	4.0		V	I_{oa} = −200 μA
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	

*For extended temperature parts only.

PIN TIMINGS

A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = 5V ±10%)

80188 Timing Requirements All Timings Measured At 1.5 Volts Unless Otherwise Noted

Symbol	Parameter	80188 (8 MHz)		Units	Test Conditions
		Min	Max		
T_{DVCL}	Data in Setup (A/D)	20		ns	
T_{CLDX}	Data in Hold (A/D)	10		ns	
T_{ARYHCH}	Asynchronous Ready (ARDY) active setup time(1)	20		ns	
T_{ARYLCL}	ARDY inactive setup time	35		ns	
T_{CLARX}	ARDY hold time	15		ns	
T_{ARYCHL}	Asynchronous Ready inactive hold time	15		ns	
T_{SRYCL}	Synchronous Ready (SRDY) Transition Setup Time(2)	20		ns	
T_{CLSRY}	SRDY Transition Hold Time(2)	15		ns	
T_{HVCL}	HOLD Setup(1)	25		ns	
T_{INVCH}	INTR, NMI, $\overline{TEST}$, TMR IN, Setup(1)	25		ns	
T_{INVCL}	DRQ0, DRQ1, Setup(1)	25		ns	
80188 Master Interface Timing Responses					
T_{CLAV}	Address Valid Delay	5	55	ns	C_L = 20–200 pF all outputs (except T_{CLTMV}) @ 8 MHz
T_{CLAX}	Address Hold	10		ns	
T_{CLAZ}	Address Float Delay	T_{CLAX}	35	ns	
T_{CHCZ}	Command Lines Float Delay		45	ns	
T_{CHCV}	Command Lines Valid Delay (after float)		55	ns	
T_{LHLL}	ALE Width	$T_{CLCL}-35$		ns	
T_{CHLH}	ALE Active Delay		35	ns	
T_{CHLL}	ALE Inactive Delay		35	ns	
T_{LLAX}	Address Hold to ALE Inactive	$T_{CHCL}-25$		ns	
T_{CLDV}	Data Valid Delay	10	44	ns	
T_{CLDOX}	Data Hold Time	10		ns	
T_{WHDX}	Data Hold after WR	$T_{CLCL}-40$		ns	
T_{CVCTV}	Control Active Delay 1	5	50	ns	
T_{CHCTV}	Control Active Delay 2	10	55	ns	
T_{CVCTX}	Control Inactive Delay	5	55	ns	
T_{CVDEX}	$\overline{DEN}$ Inactive Delay (Non-Write Cycle)	10	70	ns	

1. To guarantee recognition at next clock.
2. To guarantee proper operation.

PIN TIMINGS (Continued)

A.C. CHARACTERISTICS

(T_A = 0°C to +70°C, V_{CC} = 5V ±10%) (Continued)

80188 Master Interface Timing Responses (Continued)

Symbol	Parameter	80188 (8 MHz)		Units	Test Conditions
		Min	Max		
T_{AZRL}	Address Float to $\overline{RD}$ Active	0		ns	
T_{CLRL}	$\overline{RD}$ Active Delay	10	70	ns	
T_{CLRH}	$\overline{RD}$ Inactive Delay	10	55	ns	
T_{RHAV}	$\overline{RD}$ Inactive to Address Active	$T_{CLCL}-40$		ns	
T_{CLHAV}	HLDA Valid Delay	5	50	ns	
T_{RLRH}	$\overline{RD}$ Width	$2T_{CLCL}-50$		ns	
T_{WLWH}	$\overline{WR}$ Width	$2T_{CLCL}-40$		ns	
T_{AVLL}	Address Valid to ALE Low	$T_{CLCH}-25$		ns	
T_{CHSV}	Status Active Delay	10	55	ns	
T_{CLSH}	Status Inactive Delay	10	65	ns	
T_{CLTMV}	Timer Output Delay		60	ns	100 pF max
T_{CLRO}	Reset Delay		60	ns	
T_{CHQSV}	Queue Status Delay		35	ns	
T_{CHDX}	Status Hold Time	10		ns	
T_{AVCH}	Address Valid to Clock High	10		ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	5	65	ns	

80188 Chip-Select Timing Responses

T_{CLCSV}	Chip-Select Active Delay		66	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	35		ns	
T_{CHCSX}	Chip-Select Inactive Delay	5	35	ns	

80188 CLKIN Requirements

T_{CKIN}	CLKIN Period	62.5	250	ns	
T_{CKHL}	CLKIN Fall Time		10	ns	3.5 to 1.0V
T_{CKLH}	CLKIN Rise Time		10	ns	1.0 to 3.5V
T_{CLCK}	CLKIN Low Time	25		ns	1.5V
T_{CHCK}	CLKIN High Time	25		ns	1.5V

T_{CHCL}	CLKOUT High Time	½ T_{CLCL} − 7.5		ns	1.5V
T_{CH1CH2}	CLKOUT Rise Time		15	ns	1.0 to 3.5V
T_{CL2CL1}	CLKOUT Fall Time		15	ns	3.5 to 1.0V

Explanation of the AC Symbols

Each timing symbol has from 5 to 7 characters. The first character is always a "T" (stands for time). The other characters, depending on their positions, stand for the name of a signal or the logical status of that signal. The following is a list of all the characters and what they stand for.

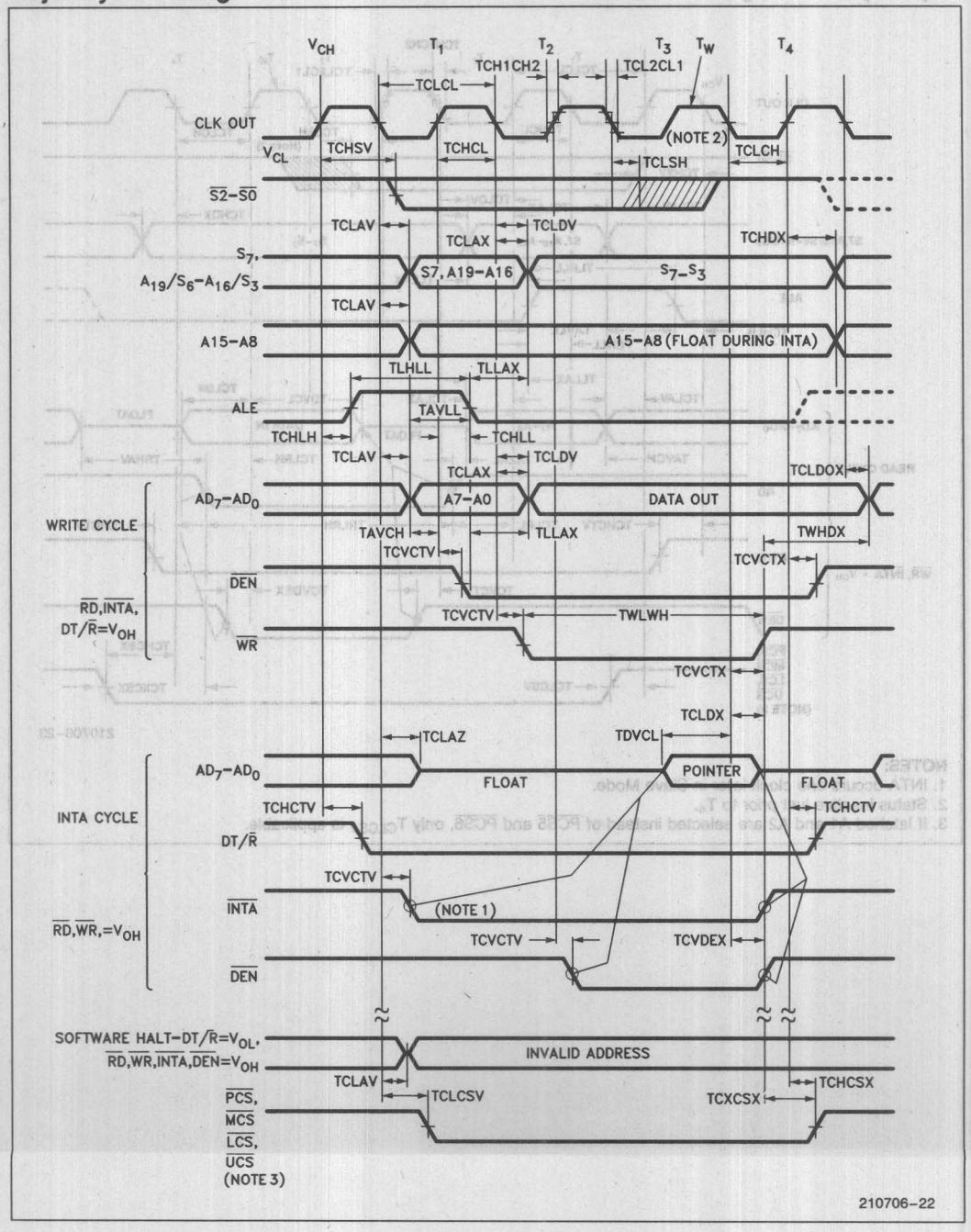
A: Address
ARY: Asynchronous Ready Input
C: Clock Output
CK: Clock Input
CS: Chip Select
CT: Control (DT/$\overline{R}$, $\overline{DEN}$, . . .)
D: Data Input
DE: $\overline{DEN}$
H: Logic Level High
IN: Input (DRQ0, TIM0, . . .)
L: Logic Level Low or ALE
O: Output
QS: Queue Status (QS1, QS2)
R: $\overline{RD}$ Signal, RESET Signal
S: Status ($\overline{S0}$, $\overline{S1}$, $\overline{S2}$)
SRY: Synchronous Ready Input
V: Valid
W: WR Signal
X: No Longer a Valid Logic Level
Z: Float

Examples:

T_{CLAV}— Time from Clock Low to Address Valid
T_{CHLH}— Time from Clock High to ALE High
T_{CLCSV}— Time from Clock LOW to Chp Select Valid

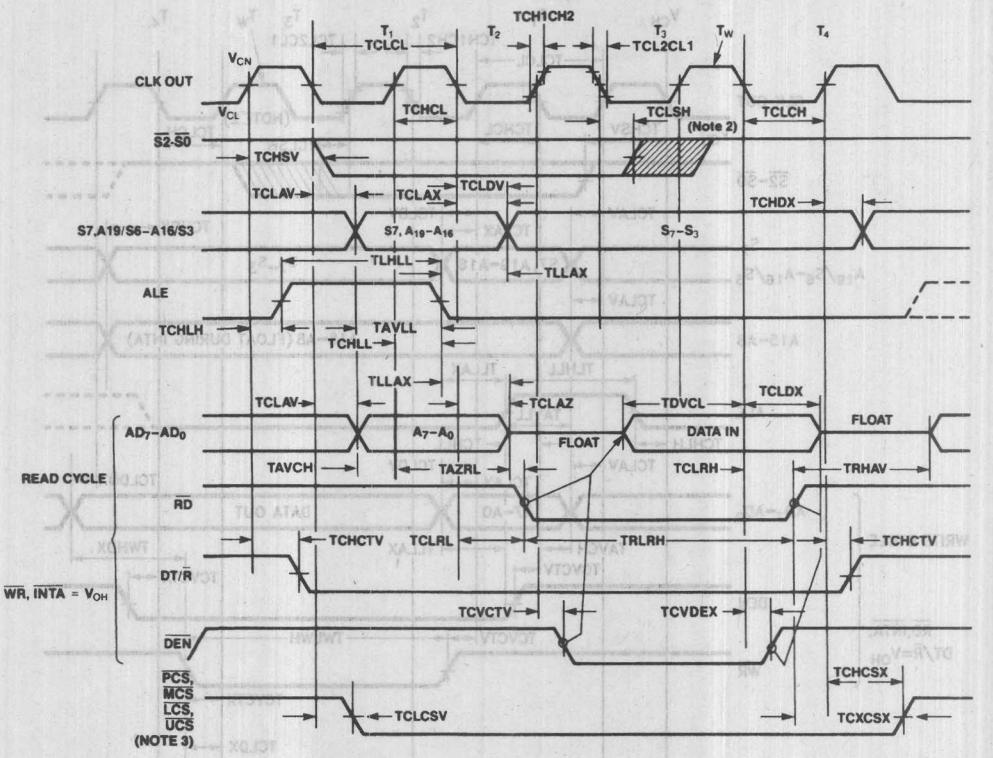
WAVEFORMS

Major Cycle Timing

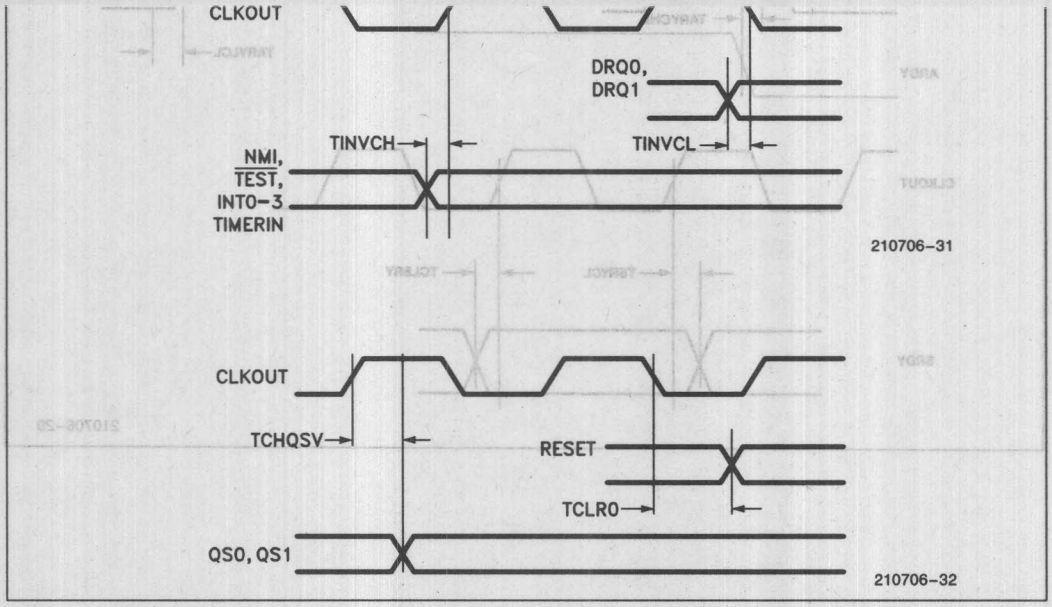


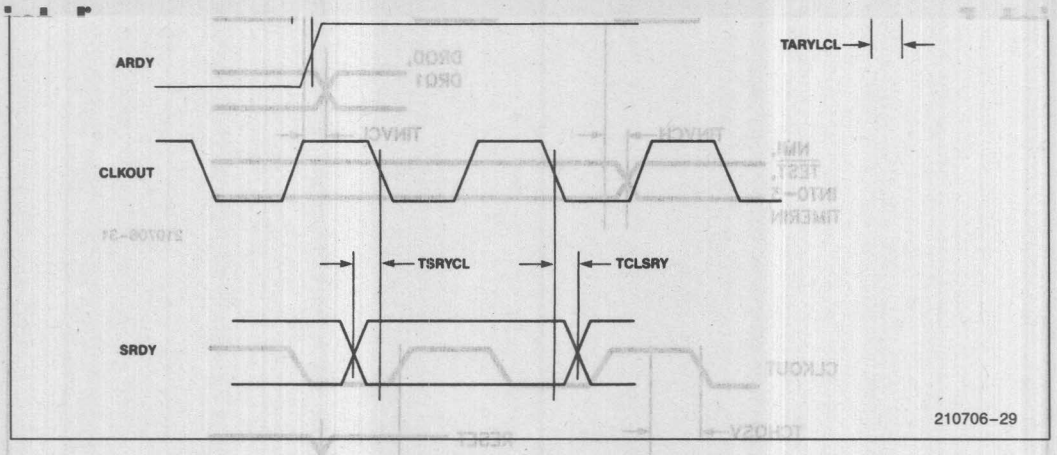
WAVEFORMS (Continued)

Major Cycle Timing (Continued)



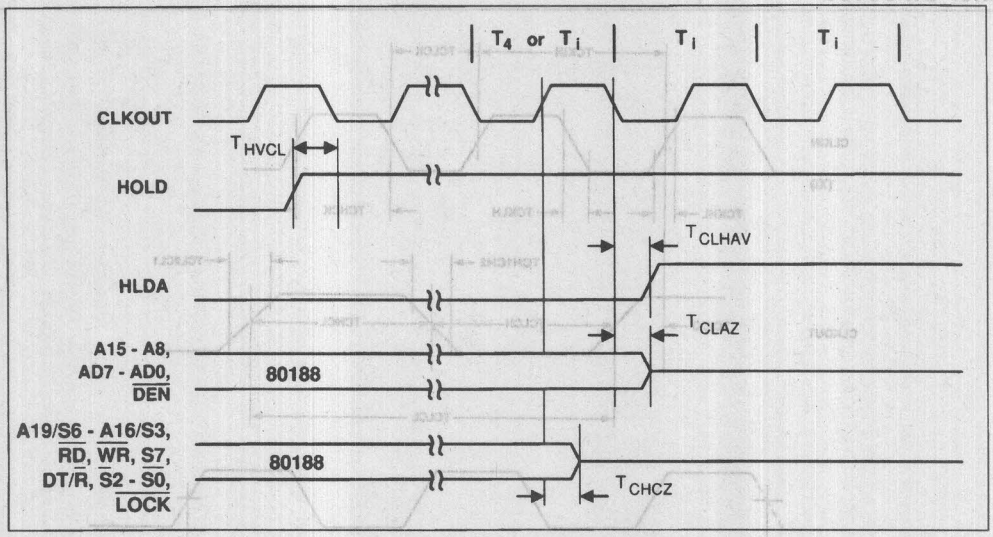
NOTES:
1. INTA occurs one clock later in Slave Mode.
2. Status inactive just prior to T_4.
3. If latched A1 and A2 are selected instead of $\overline{PCS5}$ and $\overline{PCS6}$, only T_{CLCSV} is applicable.


CLKOUT
DRQ0,
DRQ1
TINVCH
TINVCL
NMI,
TEST,
INT0–3
TIMERIN
210706–31
CLKOUT
TCHQSV
RESET
TCLR0
QS0, QS1
210706–32

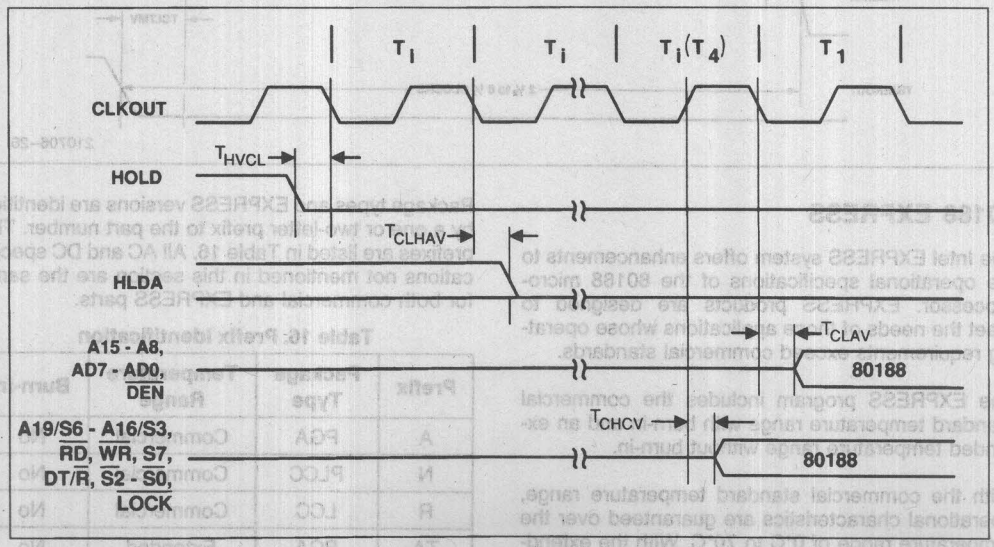

ARDY
TARYLCL
CLKOUT
TSRYCL
TCLSRY
SRDY
210706-29

WAVEFORMS (Continued)

HOLD/HLDA TIMING (Entering Hold)



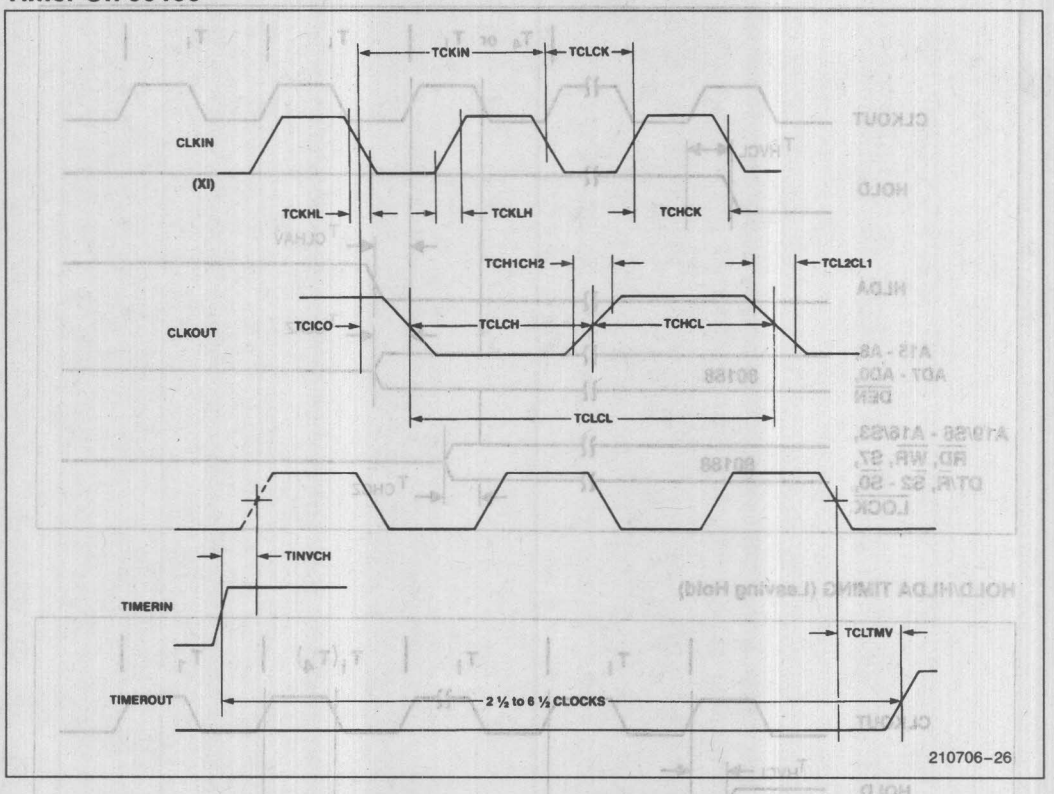
HOLD/HLDA TIMING (Leaving Hold)



210706-33

WAVEFORMS (Continued)

Timer On 80188



80188 EXPRESS

The Intel EXPRESS system offers enhancements to the operational specifications of the 80188 microprocessor. EXPRESS products are designed to meet the needs of those applications whose operating requirements exceed commercial standards.

The EXPRESS program includes the commercial standard temperature range with burn-in and an extended temperature range without burn-in.

With the commercial standard temperature range, operational characteristics are guaranteed over the temperature range of 0°C to 70°C. With the extended temperature range option, operational characteristics are guaranteed over the range of −40°C to +85°C.

The optional burn-in is dynamic, for a minimum time of 160 hours at 125°C with V_{CC} = 5.5V ±0.25V, following guidelines in MIL-STD-883, Method 1015.

Package types and EXPRESS versions are identified by a one or two-letter prefix to the part number. The prefixes are listed in Table 16. All AC and DC specifications not mentioned in this section are the same for both commercial and EXPRESS parts.

Table 16. Prefix Identification

Prefix	Package Type	Temperature Range	Burn-In
A	PGA	Commercial	No
N	PLCC	Commercial	No
R	LCC	Commercial	No
TA	PGA	Extended	No
QR	LCC	Commercial	Yes

NOTE:
Not all package/temperature range combinations are available.

80188 EXECUTION TIMINGS

A determination of 80188 program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDs occur.

All instructions which involve memory accesses can also require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the Bus Interface Unit (BIU) and execution unit.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

The 80188 8-bit BIU is noticeably limited in its performance relative to the execution unit. A sufficient number of prefetched bytes may not reside in the prefetch queue much of the time. Therefore, actual program execution time may be substantially greater than that derived from adding the instruction timings shown.

Segment register to register/memory	10001100	mod 0 reg r/m		2/15	
PUSH = Push:					
Memory	11111111	mod 1 1 0 r/m		20	
Register	0 1 0 1 0 reg			14	
Segment register	0 0 0 reg 1 1 0			13	
Immediate	0 1 1 0 1 0 s 0	data	data if s = 0	14	
PUSHA = Push All	01100000			68	
POP = Pop:					
Memory	10001111	mod 0 0 0 r/m		24	
Register	0 1 0 1 1 reg			14	
Segment register	0 0 0 reg 1 1 1	(reg≠01)		12	
POPA = Pop All	01100001			83	
XCHG = Exchange:					
Register/memory with register	1 0 0 0 0 1 1 w	mod reg r/m		4/17*	
Register with accumulator	1 0 0 1 0 reg			3	
IN = Input from:					
Fixed port	1 1 1 0 0 1 0 w	port		10*	
Variable port	1 1 1 0 1 1 0 w			8*	
OUT = Output to:					
Fixed port	1 1 1 0 0 1 1 w	port		9*	
Variable port	1 1 1 0 1 1 1 w			7*	
XLAT = Translate byte to AL	11010111			15	
LEA = Load EA to register	10001101	mod reg r/m		6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)	26	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)	26	
LAHF = Load AH with flags	10011111			2	
SAHF = Store AH into flags	10011110			3	
PUSHF = Push flags	10011100			13	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
DATA TRANSFER (Continued)						
POPF = Pop flags	10011101				12	
SEGMENT = **Segment Override:**						
CS	00101110				2	
SS	00110110				2	
DS	00111110				2	
ES	00100110				2	
ARITHMETIC						
ADD = **Add:**						
Reg/memory with register to either	000000dw	mod reg r/m			3/10*	
Immediate to register/memory	100000sw	mod 000 r/m	data	data if s w=01	4/16*	
Immediate to accumulator	0000010w	data	data if w=1		3/4	8/16-bit
ADC = **Add with carry:**						
Reg/memory with register to either	000100dw	mod reg r/m			3/10*	
Immediate to register/memory	100000sw	mod 010 r/m	data	data if s w=01	4/16*	
Immediate to accumulator	0001010w	data	data if w=1		3/4	8/16-bit
INC = **Increment:**						
Register/memory	1111111w	mod 000 r/m			3/15*	
Register	01000 reg				3	
SUB = **Subtract:**						
Reg/memory and register to either	001010dw	mod reg r/m			3/10*	
Immediate from register/memory	100000sw	mod 101 r/m	data	data if s w=01	4/16*	
Immediate from accumulator	0010110w	data	data if w=1		3/4	8/16-bit
SBB = **Subtract with borrow:**						
Reg/memory and register to either	000110dw	mod reg r/m			3/10*	
Immediate from register/memory	100000sw	mod 011 r/m	data	data if s w=01	4/16*	
Immediate from accumulator	0001110w	data	data if w=1		3/4	8/16-bit
DEC = **Decrement:**						
Register/memory	1111111w	mod 001 r/m			3/15*	
Register	01001 reg				3	
CMP = **Compare:**						
Register/memory with register	0011101w	mod reg r/m			3/10*	
Register with register/memory	0011100w	mod reg r/m			3/10*	
Immediate with register/memory	100000sw	mod 111 r/m	data	data if s w=01	3/10*	
Immediate with accumulator	0011110w	data	data if w=1		3/4	8/16-bit
NEG = Change sign register/memory	1111011w	mod 011 r/m			3/10*	
AAA = ASCII adjust for add	00110111				8	
DAA = Decimal adjust for add	00100111				4	
AAS = ASCII adjust for subtract	00111111				7	
DAS = Decimal adjust for subtract	00101111				4	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
ARITHMETIC (Continued)						
MUL = Multiply (unsigned):	1111011w	mod 100 r/m				
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43*	
IMUL = Integer multiply (signed):	1111011w	mod 101 r/m				
Register-Byte					25–28	
Register-Word					34–37	
Memory-Byte					31–34	
Memory-Word					40–43*	
IMUL = Integer Immediate multiply (signed)	011010s1	mod reg r/m	data	data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1111011w	mod 110 r/m				
Register-Byte					29	
Register-Word					38	
Memory-Byte					35	
Memory-Word					44*	
IDIV = Integer divide (signed):	1111011w	mod 111 r/m				
Register-Byte					44–52	
Register-Word					53–61	
Memory-Byte					50–58	
Memory-Word					59–67*	
AAM = ASCII adjust for multiply	11010100	00001010			19	
AAD = ASCII adjust for divide	11010101	00001010			15	
CBW = Convert byte to word	10011000				2	
CWD = Convert word to double word	10011001				4	
LOGIC						
Shift/Rotate Instructions:						
Register/Memory by 1	1101000w	mod TTT r/m			2/15	
Register/Memory by CL	1101001w	mod TTT r/m			5+n/17+n	
Register/Memory by Count	1100000w	mod TTT r/m	count		5+n/17+n	

TTT	Instruction
000	ROL
001	ROR
010	RCL
011	RCR
100	SHL/SAL
101	SHR
111	SAR

AND = And:						
Reg/memory and register to either	001000dw	mod reg r/m			3/10*	
Immediate to register/memory	1000000w	mod 100 r/m	data	data if w=1	4/16*	
Immediate to accumulator	0010010w	data	data if w=1		3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

Immediate to register/memory	1000000w	mod 1 1 0 r/m	data	data if w=1	4/16*	
Immediate to accumulator	0011010w	data	data if w=1		3/4	8/16-bit
NOT = Invert register/memory	1111011w	mod 0 1 0 r/m			3/10*	
STRING MANIPULATION:						
MOVS = Move byte/word	1010010w				14*	
CMPS = Compare byte/word	1010011w				22*	
SCAS = Scan byte/word	1010111w				15*	
LODS = Load byte/wd to AL/AX	1010110w				12*	
STOS = Store byte/wd from AL/AX	1010101w				10*	
INS = Input byte/wd from DX port	0110110w				14	
OUTS = Output byte/wd to DX port	0110111w				14	
Repeated by count in CX (REP/REPE/REPZ/REPNE/REPNZ)						
MOVS = Move string	11110010	1010010w			8+8n*	
CMPS = Compare string	1111001z	1010011w			5+22n*	
SCAS = Scan string	1111001z	1010111w			5+15n*	
LODS = Load string	11110010	1010110w			6+11n*	
STOS = Store string	11110010	1010101w			6+9n*	
INS = Input string	11110010	0110110w			8+8n*	
OUTS = Output string	11110010	0110111w			8+8n*	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
CONTROL TRANSFER			
CALL = Call:			
Direct within segment	11101000 | disp-low | disp-high	19	
Register/memory indirect within segment	11111111 | mod 010 r/m	17/27	
Direct intersegment	10011010 | segment offset segment selector	31	
Indirect intersegment	11111111 | mod 011 r/m | (mod ≠ 11)	54	
JMP = Unconditional jump:			
Short/long	11101011 | disp-low	14	
Direct within segment	11101001 | disp-low | disp-high	14	
Register/memory indirect within segment	11111111 | mod 100 r/m	11/21	
Direct intersegment	11101010 | segment offset segment selector	14	
Indirect intersegment	11111111 | mod 101 r/m | (mod ≠ 11)	34	
RET = Return from CALL:			
Within segment	11000011	20	
Within seg adding immed to SP	11000010 | data-low | data-high	22	
Intersegment	11001011	30	
Intersegment adding immediate to SP	11001010 | data-low | data-high	33	
JE/JZ = Jump on equal/zero	01110100 | disp	4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100 | disp	4/13	
JLE/JNG = Jump on less or equal/not greater	01111110 | disp	4/13	
JB/JNAE = Jump on below/not above or equal	01110010 | disp	4/13	
JBE/JNA = Jump on below or equal/not above	01110110 | disp	4/13	
JP/JPE = Jump on parity/parity even	01111010 | disp	4/13	
JO = Jump on overflow	01110000 | disp	4/13	
JS = Jump on sign	01111000 | disp	4/13	
JNE/JNZ = Jump on not equal/not zero	01110101 | disp	4/13	
JNL/JGE = Jump on not less/greater or equal	01111101 | disp	4/13	
JNLE/JG = Jump on not less or equal/greater	01111111 | disp	4/13	
JNB/JAE = Jump on not below/above or equal	01110011 | disp	4/13	
JNBE/JA = Jump on not below or equal/above	01110111 | disp	4/13	
JNP/JPO = Jump on not par/par odd	01111011 | disp	4/13	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					19	
L = 1					29	
L > 1					26+20(n−1)	
LEAVE = Leave Procedure	11001001				8	
INT = **Interrupt:**						
Type specified	11001101	type			47	
Type 3	11001100				45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	11001110				48/4	
IRET = Interrupt return	11001111				28	
BOUND = Detect value out of range	01100010	mod reg r/m			33–35	
PROCESSOR CONTROL						
CLC = Clear carry	11111000				2	
CMC = Complement carry	11110101				2	
STC = Set carry	11111001				2	
CLD = Clear direction	11111100				2	
STD = Set direction	11111101				2	
CLI = Clear interrupt	11111010				2	
STI = Set interrupt	11111011				2	
HLT = Halt	11110100				2	
WAIT = Wait	10011011				6	if $\overline{TEST}$ = 0
LOCK = Bus lock prefix	11110000				2	
ESC = Processor Extension Escape	11011TTT	mod LLL r/m			6	
	(TTT LLL are opcode to processor extension)					
NOP = No Operation	10010000				3	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.
*Note: Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field

if mod = 00 then DISP = 0*, disp-low and disp-high are absent

if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent

if mod = 10 then DISP = disp-high: disp-low

if r/m = 000 then EA = (BX) + (SI) + DISP

if r/m = 001 then EA = (BX) + (DI) + DISP

if r/m = 010 then EA = (BP) + (SI) + DISP

if r/m = 011 then EA = (BP) + (DI) + DISP

if r/m = 100 then EA = (SI) + DISP

if r/m = 101 then EA = (DI) + DISP

if r/m = 110 then EA = (BP) + DISP*

if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

REVISION HISTORY

The sections significantly revised since version -010 are:

Pin Description Table	Added note to $\overline{\text{TEST}}$ pin requiring proper RESET at power-up to configure pin as input.
	Renamed pin 44 to INT1/$\overline{\text{SELECT}}$ and pin 41 to INT3/$\overline{\text{INTA1}}$/IRQ to better describe their functions in Slave Mode.
Initialization and Processor Reset	Added reminder to drive $\overline{\text{RES}}$ pin LOW during power-up.
Major Cycle Timing Waveform	Clarified applicability of T_{CLCSV} to latched A1 and A2 in footnote.
HOLD/HLDA Timing Waveforms	Redrawn to indicate correct relationship of HOLD inactive to HLDA inactive.
Instruction Set Summary	Corrected clock count for ENTER instruction.
Slave Mode Operation	The three low order bits associated with vector generation and performing EOI are not alterable; however, the priority levels are programmable. This information is a clarification only.

The sections significantly revised since version -009 are:

Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity.
A.C. Characteristics	Added reminder that T_{SRYCL} and T_{CLSRY} must be met.
Explanation of the A.C. Symbols	New section.
Major Cycle Timing Waveforms	T_{CLRO} indicated.

The sections significantly revised since version -008 are:

Pin Description Table	Noted $\overline{\text{RES}}$ to be low more than 4 clocks. Connections to X1 and X2 clarified.
DMA Control Bit Descriptions	Moved and clarified note concerning TC condition for ST/$\overline{\text{STOP}}$ clearing during unsynchronized transfers.
Interrupt Controller, etc.	Renamed iRMX Mode to Slave Mode.
Interrupt Request Register	Noted that D0 and D1 are read/write, others read-only.
Execution Timings	Clarified effect of bus width.
A.C. Characteristics	10 MHz 80188 no longer offered.

The sections significantly revised since version -007 are:

A.C. Characteristics	Several timings changed in anticipation of test change (all listed in ns): T_{CLAV} (min.) at 10 MHz from 50 to 44; T_{CVCTV} (min.) at 8 MHz from 10 to 5; T_{CVCTV} (max.) from 70 to 50 at 8 MHz and 56 to 40 at 10 MHz.

Slave Mode Operation	The three low order bits associated with vector generation and performing EOI are not alterable; however, the priority levels are programmable. This information is a clarification only.

The sections significantly revised since version -009 are:

Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity.
A.C. Characteristics	Added reminder that T_{SRYCL} and T_{CLSRY} must be met.
Explanation of the A.C. Symbols	New section.
Major Cycle Timing Waveforms	T_{CLRO} indicated.

The sections significantly revised since version -008 are:

Pin Description Table	Noted $\overline{RES}$ to be low more than 4 clocks. Connections to X1 and X2 clarified.
DMA Control Bit Descriptions	Moved and clarified note concerning TC condition for ST/$\overline{STOP}$ clearing during unsynchronized transfers.
Interrupt Controller, etc.	Renamed iRMX Mode to Slave Mode.
Interrupt Request Register	Noted that D0 and D1 are read/write, others read-only.
Execution Timings	Clarified effect of bus width.
A.C. Characteristics	10 MHz 80186 no longer offered.

The sections significantly revised since version -007 are:

A.C. Characteristics	Several timings changed in anticipation of test change (all listed in ns). T_{CLAV} (min.) at 10 MHz from 50 to 44; T_{CVCTV} (min.) at 8 MHz from 10 to 5; T_{CVCTV} (max.) from 70 to 60 at 8 MHz and 56 to 40 at 10 MHz.

80C188
CHMOS HIGH INTEGRATION 16-BIT MICROPROCESSOR

- **Operation Modes Include:**
  - **Enhanced Mode Which Has**
    - **DRAM Refresh Control Unit**
    - **Power-Save Mode**
  - **Compatible Mode**
    - **NMOS 80188 Pin for Pin Replacement for Non-Numerics Applications**
- **Integrated Feature Set**
  - **Enhanced 80C86/C88 CPU**
  - **Clock Generator**
  - **2 Independent DMA Channels**
  - **Programmable Interrupt Controller**
  - **3 Programmable 16-Bit Timers**
  - **Dynamic RAM Refresh Control Unit**
  - **Programmable Memory and Peripheral Chip Select Logic**
  - **Programmable Wait State Generator**
  - **Local Bus Controller**
  - **Power Save Mode**
  - **System-Level Testing Support (High Impedance Test Mode)**
- **Available in 16 MHz (80C188-16), 12.5 MHz (80C188-12) and 10 MHz (80C188) Versions**
- **Direct Addressing Capability to 1 MByte Memory and 64 KByte I/O**
- **Completely Object Code Compatible with All Existing 8086/8088 Software and Also Has 10 Additional Instructions over 8086/8088**
- **Complete System Development Support**
  - **All 8088 and NMOS 80188 Software Development Tools Can Be Used for 80C186 System Development**
    - **ASM86 Assembler, PL/M-86, Pascal-86, Fortran-86, C-86 and System Utilities**
    - **In-Circuit-Emulator (ICE™-188)**
- **Available in 68 Pin:**
  - **Plastic Leaded Chip Carrier (PLCC)**
  - **Ceramic Pin Grid Array (PGA)**
  - **Ceramic Leadless Chip Carrier (JEDEC A Package)**

  (See Packaging Outlines and Dimensions, Order Number 231369)
- **Available in EXPRESS Extended Temperature Range (−40°C to +85°C)**

The Intel 80C188 is a CHMOS high integration microprocessor. It has features which are new to the 80186 family which include a DRAM refresh control unit and power-save mode. When used in "compatible" mode, the 80C188 is 100% pin-for-pin compatible with the NMOS 80188 (except for 8087 applications). The "enhanced" mode of operation allows the full feature set of the 80C188 to be used. The 80C188 is upward compatible with 8086 and 8088 software and fully compatible with 80186 and 80188 software, except for numerics applications.

October 1989
Order Number: 270432-004

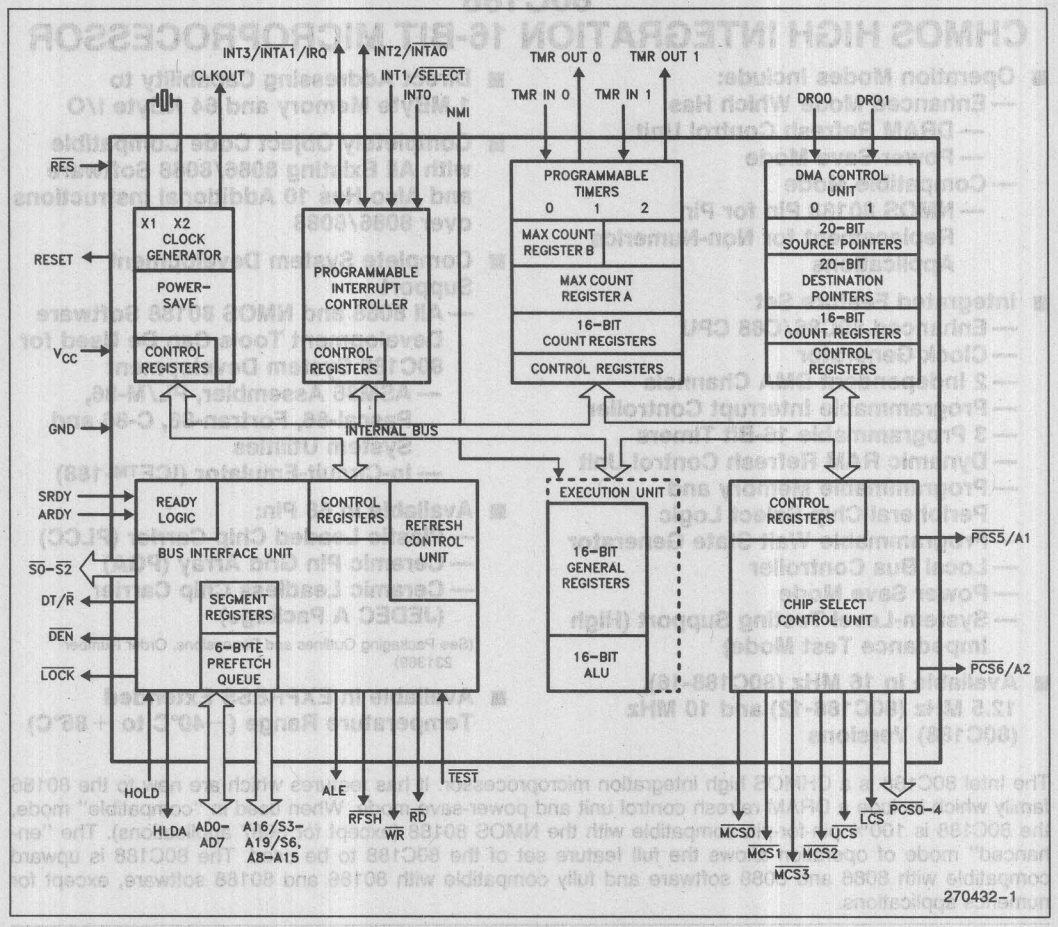


Figure 1. 80C188 Block Diagram

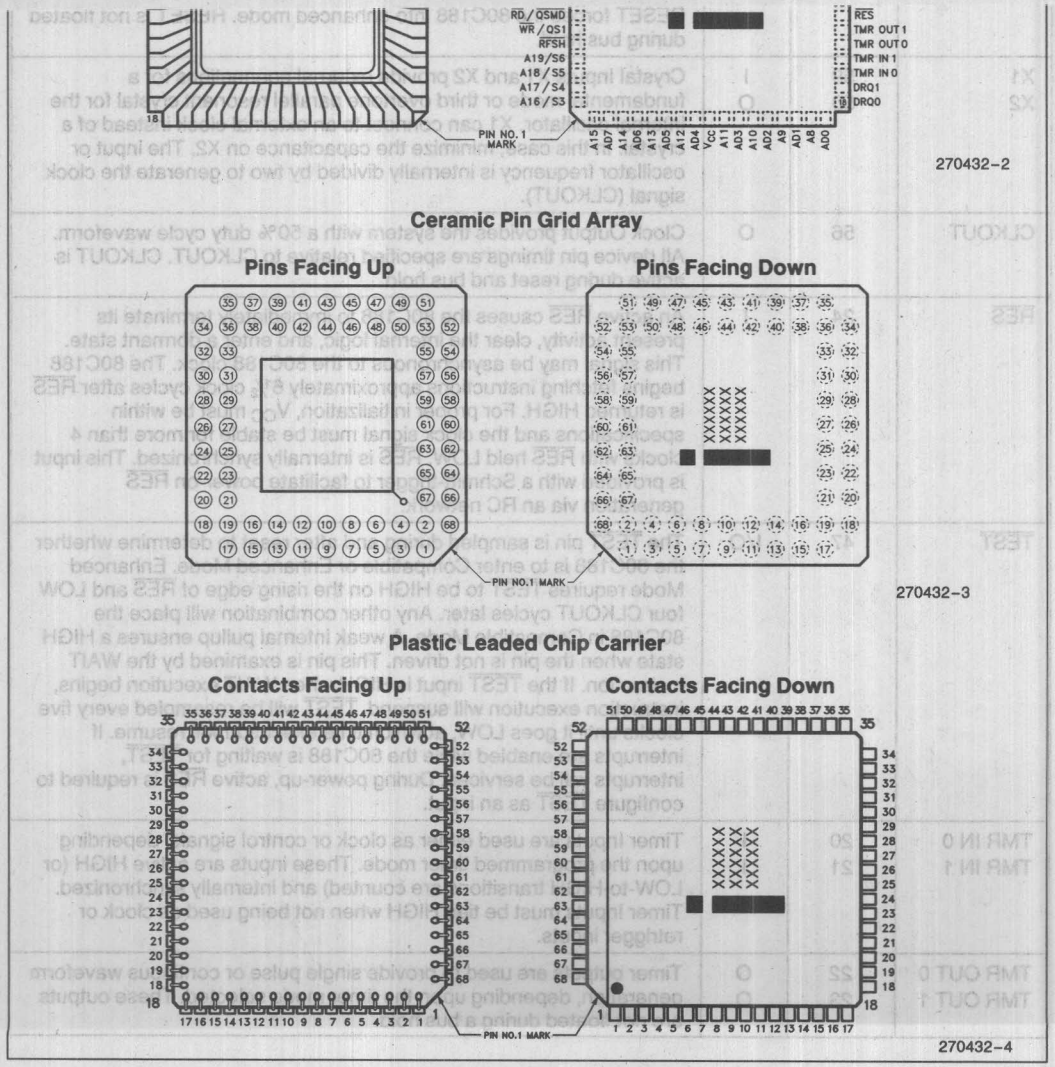


Figure 2. 80C188 Pinout Diagrams

Table 1. 80C188 Pin Description

Symbol	Pin No.	Type	Name and Function
V_{CC}	9 43	I I	System Power: +5 volt power supply.
V_{SS}	26 60	I I	System Ground.
RESET	57	O	RESET Output indicates that the 80C188 CPU is being reset, and can be used as a system reset. It is active HIGH, synchronized with the processor clock, and lasts an integer number of clock periods corresponding to the length of the $\overline{RES}$ signal. Reset goes inactive 2 clockout periods after $\overline{RES}$ goes inactive. When tied to the $\overline{TEST}$ pin, RESET forces the 80C188 into enhanced mode. RESET is not floated during bus hold.
X1 X2	59 58	I O	Crystal Inputs X1 and X2 provide external connections for a fundamental mode or third overtone parallel resonant crystal for the internal oscillator. X1 can connect to an external clock instead of a crystal. In this case, minimize the capacitance on X2. The input or oscillator frequency is internally divided by two to generate the clock signal (CLKOUT).
CLKOUT	56	O	Clock Output provides the system with a 50% duty cycle waveform. All device pin timings are specified relative to CLKOUT. CLKOUT is active during reset and bus hold.
$\overline{RES}$	24	I	An active $\overline{RES}$ causes the 80C188 to immediately terminate its present activity, clear the internal logic, and enter a dormant state. This signal may be asynchronous to the 80C188 clock. The 80C188 begins fetching instructions approximately 6½ clock cycles after $\overline{RES}$ is returned HIGH. For proper initialization, V_{CC} must be within specifications and the clock signal must be stable for more than 4 clocks with $\overline{RES}$ held LOW. $\overline{RES}$ is internally synchronized. This input is provided with a Schmitt-trigger to facilitate power-on $\overline{RES}$ generation via an RC network.
$\overline{TEST}$	47	I/O	The $\overline{TEST}$ pin is sampled during and after reset to determine whether the 80C188 is to enter Compatible or Enhanced Mode. Enhanced Mode requires $\overline{TEST}$ to be HIGH on the rising edge of $\overline{RES}$ and LOW four CLKOUT cycles later. Any other combination will place the 80C188 in Compatible Mode. A weak internal pullup ensures a HIGH state when the pin is not driven. This pin is examined by the WAIT instruction. If the $\overline{TEST}$ input is HIGH when WAIT execution begins, instruction execution will suspend. $\overline{TEST}$ will be resampled every five clocks until it goes LOW, at which time execution will resume. If interrupts are enabled while the 80C188 is waiting for $\overline{TEST}$, interrupts will be serviced. During power-up, active $\overline{RES}$ is required to configure $\overline{TEST}$ as an input.
TMR IN 0 TMR IN 1	20 21	I I	Timer Inputs are used either as clock or control signals, depending upon the programmed timer mode. These inputs are active HIGH (or LOW-to-HIGH transitions are counted) and internally synchronized. Timer Inputs must be tied HIGH when not being used as clock or retrigger inputs.
TMR OUT 0 TMR OUT 1	22 23	O O	Timer outputs are used to provide single pulse or continous waveform generation, depending upon the timer mode selected. These outputs are not floated during a bus hold.

Table 1. 80C188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
DRQ0 DRQ1	18 19	I I	DMA Request is asserted HIGH by an external device when it is ready for DMA Channel 0 or 1 to perform a transfer. These signals are level-triggered and internally synchronized.
NMI	46	I	The Non-Maskable Interrupt input causes a Type 2 interrupt. An NMI transition from LOW to HIGH is latched and synchronized internally, and initiates the interrupt at the next instruction boundary. NMI must be asserted for at least one CLKOUT period. The Non-Maskable Interrupt cannot be avoided by programming.
INT0 INT1/$\overline{\text{SELECT}}$ INT2/$\overline{\text{INTA0}}$ INT3/$\overline{\text{INTA1}}$/IRQ	45 44 42 41	I I I/O I/O	Maskable Interrupt Requests can be requested by activating one of these pins. When configured as inputs, these pins are active HIGH. Interrupt Requests are synchronized internally. INT2 and INT3 may be configured to provide active-LOW interrupt-acknowledge output signals. All interrupt inputs may be configured to be either edge- or level-triggered. To ensure recognition, all interrupt requests must remain active until the interrupt is acknowledged. When slave mode is selected, the function of these pins changes (see Interrupt Controller section of this data sheet).
A19/S6 A18/S5 A17/S4 A16/S3	65 66 67 68	O O O O	Address Bus Outputs (16–19) and Bus Cycle Status (3–6) indicate the four most significant address bits during T_1. These signals are active HIGH. During T_2, T_3, T_W, and T_4, status information is available on these lines as encoded below: During T_2, T_3, T_W, and T_4, the S6 pin is LOW to indicate a CPU-initiated bus cycle or HIGH to indicate a DMA-initiated bus cycle. During the same T-states, S3, S4, and S5 are always LOW. These outputs are floated during a bus hold or reset.
A15 A14 A13 A12 A11 A10 A9 A8	1 3 5 7 10 12 14 16	O O O O O O O O	Address-Only Bus (15–8) contains valid addresses from T_1–T_4. The bus is active high. These outputs are floated during a bus hold or reset.
AD7 AD6 AD5 AD4 AD3 AD2 AD1 AD0	2 4 6 8 11 13 15 17	I/O I/O I/O I/O I/O I/O I/O I/O	Address/Data Bus (7–0) signals constitute the time multiplexed memory or I/O address (T_1) and data (T_2, T_3, T_W, and T_4) bus. The bus is active high. These pins are floated during a bus hold or reset.
$\overline{\text{RFSH}}$	64	O	In compatible mode, $\overline{\text{RFSH}}$ is HIGH. In enhanced mode, $\overline{\text{RFSH}}$ is asserted LOW to signify a refresh bus cycle. The $\overline{\text{RFSH}}$ output pin floats during bus hold or reset, regardless of operating mode.

Table 1. 80C186 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
ALE/QS0	61	O	Address Latch Enable/Queue Status 0 is provided by the 80C188 to latch the address. ALE is active HIGH, with addresses guaranteed valid on the trailing edge.
$\overline{WR}$/QS1	63	O	Write Strobe/Queue Status 1 indicates that the data on the bus is to be written into a memory or an I/O device. It is active LOW, and floats during bus hold or reset. When the 80C188 is in queue status mode, the ALE/QS0 and $\overline{WR}$/QS1 pins provide information about processor/instruction queue interaction.

QS1	QS0	Queue Operation
0	0	No queue operation
0	1	First opcode byte fetched from the queue
1	1	Subsequent byte fetched from the queue
1	0	Empty the queue

$\overline{RD}$/$\overline{QSMD}$	62	O/I	Read Strobe is an active LOW signal which indicates that the 80C188 is performing a memory or I/O read cycle. It is guaranteed not to go LOW before the A/D bus is floated. An internal pull-up ensures that $\overline{RD}$/$\overline{QSMD}$ is HIGH during RESET. Following RESET the pin is sampled to determine whether the 80C188 is to provide ALE, $\overline{RD}$ and $\overline{WR}$, or queue status information. To enable Queue Status Mode, $\overline{RD}$ must be connected to GND. $\overline{RD}$ will float during bus HOLD.
ARDY	55	I	Asynchronous Ready informs the 80C188 that the addressed memory space or I/O device will complete a data transfer. The ARDY pin accepts a rising edge that is asynchronous to CLKOUT and is active HIGH. The falling edge of ARDY must be synchronized to the 80C188 clock. Connecting ARDY HIGH will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the SRDY pin.
SRDY	49	I	Synchronous Ready informs the 80C188 that the addressed memory space or I/O device will complete a data transfer. The SRDY pin accepts an active-HIGH input synchronized to CLKOUT. The use of SRDY allows a relaxed system timing over ARDY. This is accomplished by elimination of the one-half clock cycle required to internally synchronize the ARDY input signal. Connecting SRDY high will always assert the ready condition to the CPU. If this line is unused, it should be tied LOW to yield control to the ARDY pin.

			$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	Bus Cycle Initiated
			0	0	0	Interrupt Acknowledge
			0	0	1	Read I/O
			0	1	0	Write I/O
			0	1	1	Halt
			1	0	0	Instruction Fetch
			1	0	1	Read Data from Memory
			1	1	0	Write Data to Memory
			1	1	1	Passive (no bus cycle)
			The status pins float during HOLD. $\overline{S2}$ may be used as a logical M/$\overline{IO}$ indicator, and $\overline{S1}$ as a DT/$\overline{R}$ indicator.			
HOLD HLDA	50 51	I O	HOLD indicates that another bus master is requesting the local bus. The HOLD input is active HIGH. The 80C188 generates HLDA (HIGH) in response to a HOLD request. Simultaneous with the issuance of HLDA, the 80C188 will float the local bus and control lines. After HOLD is detected as being LOW, the 80C188 will lower HLDA. When the 80C188 needs to run another bus cycle, it will again drive the local bus and control lines. In Enhanced Mode, HLDA will go low when a DRAM refresh cycle is pending in the 80C188 and an external bus master has control of the bus. It will be up to the external master to relinquish the bus by lowering HOLD so that the 80C188 may execute the refresh cycle.			
$\overline{UCS}$	34	O/I	Upper Memory Chip Select is an active LOW output whenever a memory reference is made to the defined upper portion (1K–256K block) of memory. $\overline{UCS}$ does not float during bus hold. The address range activating $\overline{UCS}$ is software programmable. $\overline{UCS}$ and $\overline{LCS}$ are sampled upon the rising edge of $\overline{RES}$. If both pins are held low, the 80C188 will enter ONCE Mode. In ONCE Mode all pins assume a high impedance state and remain so until a subsequent RESET. $\overline{UCS}$ has a weak internal pullup that is active during RESET to ensure that the 80C188 does not enter the ONCE mode inadvertently.			

Table 1. 80C188 Pin Description (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{LCS}$	33	O/I	Lower Memory Chip Select is active LOW whenever a memory reference is made to the defined lower portion (1K–256K) of memory. $\overline{LCS}$ does not float during bus HOLD. The address range activating $\overline{LCS}$ is software programmable. $\overline{UCS}$ and $\overline{LCS}$ are sampled upon the rising edge of $\overline{RES}$. If both pins are held low, the 80C186 will enter ONCE Mode. In ONCE Mode all pins assume a high impedance state and remain so until a subsequent RESET. $\overline{LCS}$ has a weak internal pullup that is active only during RESET to ensure that the 80C188 does not enter ONCE Mode inadvertently.
$\overline{MCS0}$ $\overline{MCS1}$ $\overline{MCS2}$ $\overline{MCS3}$	38 37 36 35	O O O O	Mid-Range Memory Chip Select signals are active LOW when a memory reference is made to the defined mid-range portion of memory (8K–512K). These lines do not float during bus HOLD. The address ranges activating $\overline{MCS0}$–3 are software programmable.
$\overline{PCS0}$ $\overline{PCS1}$ $\overline{PCS2}$ $\overline{PCS3}$ $\overline{PCS4}$	25 27 28 29 30	O O O O O	Peripheral Chip Select signals 0–4 are active LOW when a reference is made to the defined peripheral area (64K I/O space or 1 Mbyte memory space). These lines do not float during bus HOLD. The address ranges activating $\overline{PCS0}$–4 are software programmable.
$\overline{PCS5}$/A1	31	O	Peripheral Chip Select 5 or Latched A1 may be programmed to provide a sixth peripheral chip select, or to provide an internally latched A1 signal. The address range activating $\overline{PCS5}$ is software-programmable. $\overline{PCS5}$/A1 does not float during bus HOLD. When programmed to provide latched A1, this pin will retain the previously latched value during HOLD.
$\overline{PCS6}$/A2	32	O	Peripheral Chip Select 6 or Latched A2 may be programmed to provide a seventh peripheral chip select, or to provide an internally latched A2 signal. The address range activating $\overline{PCS6}$ is software-programmable. $\overline{PCS6}$/A2 does not float during bus HOLD. When programmed to provide latched A2, this pin will retain the previously latched value during HOLD.
DT/$\overline{R}$	40	O	Data Transmit/Receive controls the direction of data flow through an external data bus transceiver. When LOW, data is transferred to the 80C188. When HIGH the 80C188 places write data on the data bus. DT/$\overline{R}$ floats during a bus hold or RESET.
$\overline{DEN}$	39	O	Data Enable is provided as a data bus transceiver output enable. $\overline{DEN}$ is active LOW during each memory and I/O access. $\overline{DEN}$ is HIGH whenever DT/$\overline{R}$ changes state. During RESET, $\overline{DEN}$ is driven HIGH for one clock, then floated. $\overline{DEN}$ also floats during HOLD.

FUNCTIONAL DESCRIPTION

Introduction

The following Functional Description describes the base architecture of the 80C188. The 80C188 is a very high integration 16-bit microprocessor. It combines 15–20 of the most common microprocessor system components onto one chip. The 80C188 is object code compatible with the 8086/8088 microprocessors and adds 10 new instruction types to the 8086/8088 instruction set.

The 80C188 has two major modes of operation, Compatible and Enhanced. In Compatible Mode the 80C188 is completely compatible with NMOS 80188, with the exception of 8087 support. The Enhanced mode adds two new features to the system design. These are Power-Save control and Dynamic RAM refresh.

80C188 BASE ARCHITECTURE

The 8086, 8088, 80186, and 80188 families all contain the same basic set of registers, instructions, and addressing modes. The 80C188 processor is upward compatible with the 8086 and 8088 CPUs.

Register Set

The 80C188 base architecture has fourteen registers as shown in Figures 3a and 3b. These registers are grouped into the following categories.

General Registers

Eight 16-bit general purpose registers may be used for arithmetic and logical operands. Four of these (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers.

Segment Registers

Four 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data. (For usage, refer to Memory Organization.)

Base and Index Registers

Four of the general purpose registers may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Status and Control Registers

Two 16-bit special purpose registers record or alter certain aspects of the 80C188 processor state. These are the Instruction Pointer Register, which contains the offset address of the next sequential instruction to be executed, and the Status Word Register, which contains status and control flag bits (see Figures 3a and 3b).

Status Word Description

The Status Word records specific characteristics of the result of logical and arithmetic instructions (bits 0, 2, 4, 6, 7, and 11) and controls the operation of the 80C186 within a given operating mode (bits 8, 9, and 10). The Status Word Register is 16-bits wide. The function of the Status Word bits is shown in Table 2.

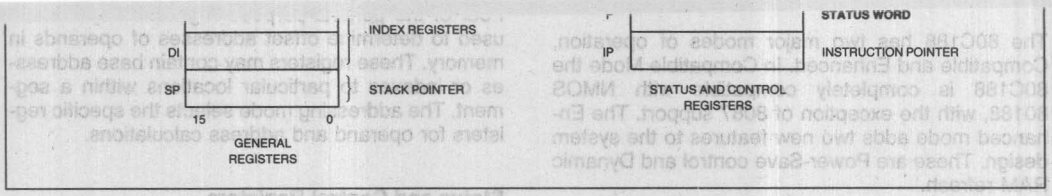


Figure 3a. 80C188 Register Set

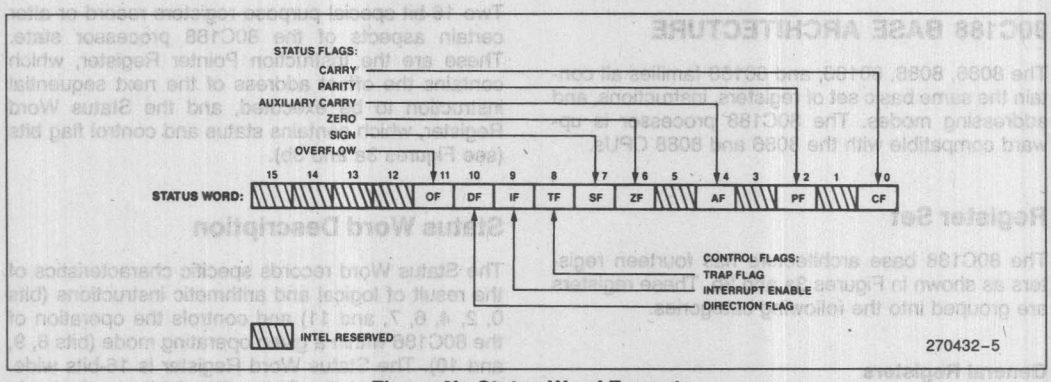


Figure 3b. Status Word Format

Table 2. Status Word Bit Functions

Bit Position	Name	Function
0	CF	Carry Flag—Set on high-order bit carry or borrow; cleared otherwise
2	PF	Parity Flag—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise
4	AF	Set on carry from or borrow to the low order four bits of AL; cleared otherwise
6	ZF	Zero Flag—Set if result is zero; cleared otherwise
7	SF	Sign Flag—Set equal to high-order bit of result (0 if positive, 1 if negative)
8	TF	Single Step Flag—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	Interrupt-enable Flag—When set, maskable interrupts will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	Direction Flag—Causes string instructions to auto decrement the appropriate index register when set. Clearing DF causes auto increment.
11	OF	Overflow Flag—Set if the signed result cannot be expressed within the number of bits in the destination operand; cleared otherwise

Instruction Set

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80C188 instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory. Specific operand addressing modes are discussed later in this data sheet.

Memory Organization

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base values are contained in one of four internal segment register (code, data, stack, extra). The physical address is calculated by shifting the base value LEFT by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 5). This allows for a 1 MByte physical address size.

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for physical address generation is implied by the addressing mode used (see Table 3). These rules follow the way programs are written (see Figure 6) as independent modules that require areas for code and data, a stack, and access to external data areas.

Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

GENERAL PURPOSE	
MOV	Move byte or word
PUSH	Push word onto stack
POP	Pop word off stack
PUSHA	Push all registers on stack
POPA	Pop all registers from stack
XCHG	Exchange byte or word
XLAT	Translate byte
INPUT/OUTPUT	
IN	Input byte or word
OUT	Output byte or word
ADDRESS OBJECT	
LEA	Load effective address
LDS	Load pointer using DS
LES	Load pointer using ES
FLAG TRANSFER	
LAHF	Load AH register from flags
SAHF	Store AH register in flags
PUSHF	Push flags onto stack
POPF	Pop flags off stack
ADDITION	
ADD	Add byte or word
ADC	Add byte or word with carry
INC	Increment byte or word by 1
AAA	ASCII adjust for addition
DAA	Decimal adjust for addition
SUBTRACTION	
SUB	Subtract byte or word
SBB	Subtract byte or word with borrow
DEC	Decrement byte or word by 1
NEG	Negate byte or word
CMP	Compare byte or word
AAS	ASCII adjust for subtraction
DAS	Decimal adjust for subtraction
MULTIPLICATION	
MUL	Multiply byte or word unsigned
IMUL	Integer multiply byte or word
AAM	ASCII adjust for multiply
DIVISION	
DIV	Divide byte or word unsigned
IDIV	Integer divide byte or word
AAD	ASCII adjust for division
CBW	Convert byte to word
CWD	Convert word to doubleword

MOVS	Move byte or word string
INS	Input bytes or word string
OUTS	Output bytes or word string
CMPS	Compare byte or word string
SCAS	Scan byte or word string
LODS	Load byte or word string
STOS	Store byte or word string
REP	Repeat
REPE/REPZ	Repeat while equal/zero
REPNE/REPNZ	Repeat while not equal/not zero
LOGICALS	
NOT	"Not" byte or word
AND	"And" byte or word
OR	"Inclusive or" byte or word
XOR	"Exclusive or" byte or word
TEST	"Test" byte or word
SHIFTS	
SHL/SAL	Shift logical/arithmetic left byte or word
SHR	Shift logical right byte or word
SAR	Shift arithmetic right byte or word
ROTATES	
ROL	Rotate left byte or word
ROR	Rotate right byte or word
RCL	Rotate through carry left byte or word
RCR	Rotate through carry right byte or word
FLAG OPERATIONS	
STC	Set carry flag
CLC	Clear carry flag
CMC	Complement carry flag
STD	Set direction flag
CLD	Clear direction flag
STI	Set interrupt enable flag
CLI	Clear interrupt enable flag
EXTERNAL SYNCHRONIZATION	
HLT	Halt until interrupt or reset
WAIT	Wait for $\overline{\text{TEST}}$ pin active
LOCK	Lock bus during next instruction
NO OPERATION	
NOP	No operation
HIGH LEVEL INSTRUCTIONS	
ENTER	Format stack for procedure entry
LEAVE	Restore stack for procedure exit
BOUND	Detects values outside prescribed range

Figure 4. 80C188 Instruction Set

CONDITIONAL TRANSFERS	
JA/JNBE	Jump if above/not below nor equal
JAE/JNB	Jump if above or equal/not below
JB/JNAE	Jump if below/not above nor equal
JBE/JNA	Jump if below or equal/not above
JC	Jump if carry
JE/JZ	Jump if equal/zero
JG/JNLE	Jump if greater/not less nor equal
JGE/JNL	Jump if greater or equal/not less
JL/JNGE	Jump if less/not greater nor equal
JLE/JNG	Jump if less or equal/not greater
JNC	Jump if not carry
JNE/JNZ	Jump if not equal/not zero
JNO	Jump if not overflow
JNP/JPO	Jump if not parity/parity odd
JNS	Jump if not sign

JO	Jump if overflow
JP/JPE	Jump if parity/parity even
JS	Jump if sign
UNCONDITIONAL TRANSFERS	
CALL	Call procedure
RET	Return from procedure
JMP	Jump
ITERATION CONTROLS	
LOOP	Loop
LOOPE/LOOPZ	Loop if equal/zero
LOOPNE/LOOPNZ	Loop if not equal/not zero
JCXZ	Jump if register CX = 0
INTERRUPTS	
INT	Interrupt
INTO	Interrupt if overflow
IRET	Interrupt return

Figure 4. 80C188 Instruction Set (Continued)

To access operands that do not reside in one of the four immediately available segments, a full 32-bit pointer can be used to reload both the base (segment) and offset values.

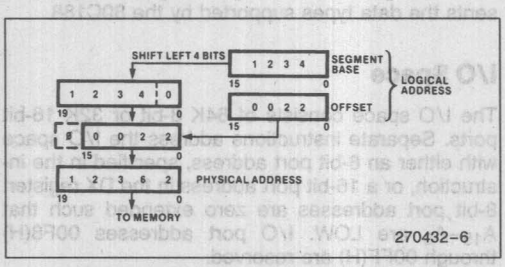


Figure 5. Two Component Address

Table 3. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data.
Stack	Stack (SS)	All stack pushes and pops; any memory references which use BP Register as a base register.
External Data (Global)	Extra (ES)	All string instruction references which use the DI register as an index.
Local Data	Data (DS)	All other data references.

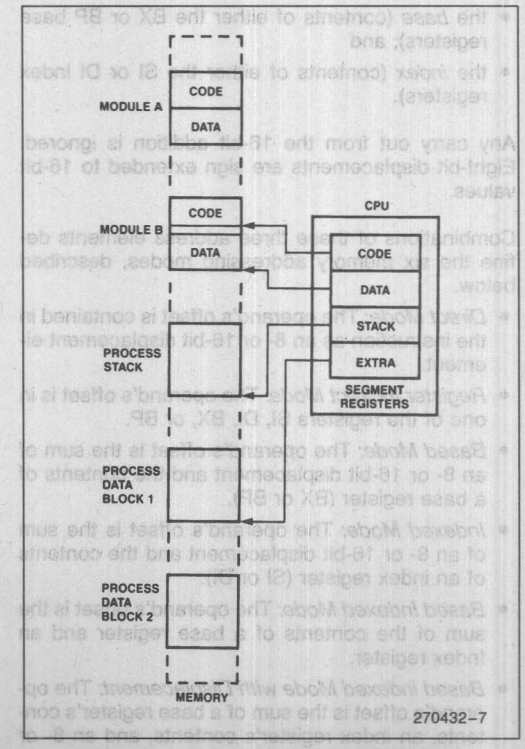


Figure 6. Segmented Memory Helps Structure Software

Addressing Modes

The 80C188 provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

Any carry out from the 16-bit addition is ignored. Eight-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an Index register.
- *Based indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

Data Types

The 80C188 directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or a 16-bit word. All operations assume a 2's complement representation.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or a 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component or a 16-bit segment base component in addition to a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 to 64K bytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4-bits) of the byte.

In general, individual data elements must fit within defined segment limits. Figure 7 graphically represents the data types supported by the 80C188.

I/O Space

The I/O space consists of 64K 8-bit or 32K 16-bit ports. Separate instructions address the I/O space with either an 8-bit port address, specified in the instruction, or a 16-bit port address in the DX register. 8-bit port addresses are zero extended such that A_{15}–A_8 are LOW. I/O port addresses 00F8(H) through 00FF(H) are reserved.

Interrupts

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (Status Word) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, INT instructions, and instruction exceptions. Hardware initiated interrupts occur in response to an external input and are classified as non-maskable or maskable.

Programs may cause an interrupt with an INT instruction. Instruction exceptions occur when an unusual condition, which prevents further instruction processing, is detected while attempting to execute an instruction. If the exception was caused by attempted execution of an ESC instruction, the return instruction will point to the ESC instruction, or to the segment override prefix immediately preceding

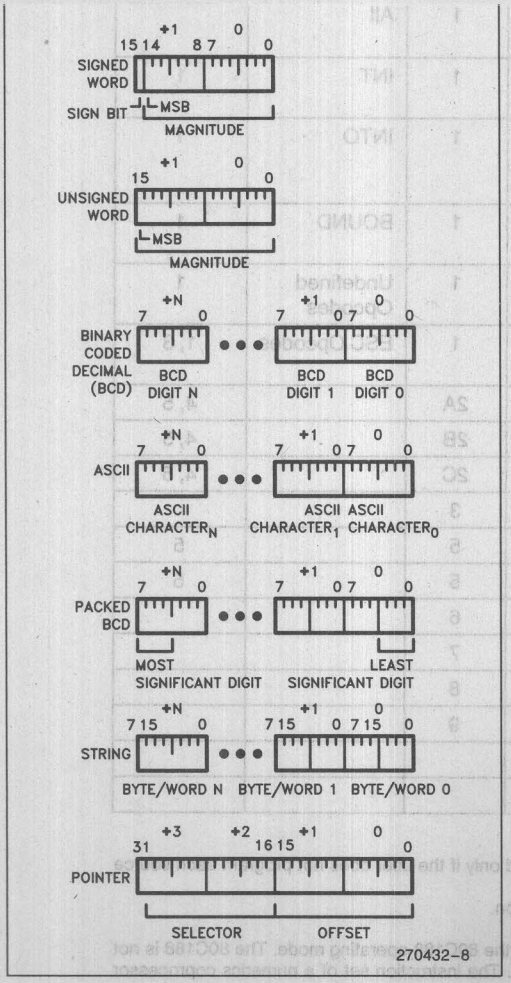


Figure 7. 80C188 Supported Data Types

Non-maskable hardware interrupts use a predefined internally supplied vector.

Interrupt Sources

The 80C188 can service interrupts generated by software or hardware. The software interrupts are generated by specific instructions (INT, ESC, unused OP, etc.) or the results of conditions specified by instructions (array bounds check, INT0, DIV, IDIV, etc.). All interrupt sources are serviced by an indirect call through an element of a vector table. This vector table is indexed by using the interrupt vector type (Table 4), multiplied by four. All hardware-generated interrupts are sampled at the end of each instruction. Thus, the software interrupts will begin service first. Once the service routine is entered and interrupts are enabled, any hardware source of sufficient priority can interrupt the service routine in progress.

Those pre-defined 80C188 interrupts which cannot be masked by programming are described below.

DIVIDE ERROR EXCEPTION (TYPE 0)

Generated when a DIV or IDIV instruction quotient cannot be expressed in the number of bits in the destination.

SINGLE-STEP INTERRUPT (TYPE 1)

Generated after most instructions if the TF flag in the status word is set. This interrupt allows programs to execute one instruction at a time. Interrupts will not be generated after prefix instructions (e.g., REP), instructions which modify segment registers (e.g., POP DS), or the WAIT instruction. Vectoring to the single-step interrupt service routine clears the TF bit. An IRET instruction in the interrupt service routine restores the TF bit to logic "1" and transfers control to the next instruction to be single-stepped.

NON-MASKABLE INTERRUPT—NMI (TYPE 2)

An external interrupt source which is serviced regardless of the state of the IF bit. No external acknowledge sequence is performed. The IF bit is cleared at the beginning of an NMI interrupt to prevent maskable interrupts from being serviced. A typical use of NMI would be to activate a power failure routine.

Table 4. 80C188 Interrupt Vectors

Interrupt Name	Vector Type	Vector Address	Default Priority	Related Instructions	Applicable Notes
Divide Error Exception	0	00H	1	DIV, IDIV	1
Single Step Interrupt	1	04H	1A	All	2
Non-Maskable Interrupt (NMI)	2	08H	1	All	
Breakpoint Interrupt	3	0CH	1	INT	1
INTO Detected Overflow Exception	4	10H	1	INTO	1
Array Bounds Exception	5	14H	1	BOUND	1
Unused-Opcode Exception	6	18H	1	Undefined Opcodes	1
ESC Opcode Exception	7	1CH	1	ESC Opcodes	1, 3
Timer 0 Interrupt	8	20H	2A		4, 5
Timer 1 Interrupt	18	48H	2B		4, 5
Timer 2 Interrupt	19	4CH	2C		4, 5
Reserved	9	24H	3		
DMA 0 Interrupt	10	28H	5		5
DMA 1 Interrupt	11	2CH	5		5
INT0 Interrupt	12	30H	6		
INT1 Interrupt	13	34H	7		
INT2 Interrupt	14	38H	8		
INT3 Interrupt	15	3CH	9		
Reserved	16, 17	40H, 44H			
Reserved	20–31	50H . . . 7CH			

NOTES:
Default priorities for the interrupt sources are used only if the user does not program each source to a unique priority level.
1. Generated as a result of an instruction execution.
2. Performed in same manner as 8088.
3. An ESC opcode will cause a trap regardless of the 80C188 operating mode. The 80C188 is not directly compatible with the 80188 in this respect. The instruction set of a numerics coprocessor *cannot be executed.*
4. All three timers constitute one source of request to the interrupt controller. As such, they share the same priority level with respect to other interrupt sources. However, the timers have a defined priority order among themselves (2A > 2B > 2C).
5. The vector type numbers for these sources are programmable in Slave Mode.

BREAKPOINT INTERRUPT (TYPE 3)

A one-byte version of the INT instruction. It uses 12 as an index into the service routine address table (because it is a type 3 interrupt).

INTO DETECTED OVERFLOW EXCEPTION (TYPE 4)

Generated during an INTO instruction if the 0F bit is set.

ARRAY BOUNDS EXCEPTION (TYPE 5)

Generated during a BOUND instruction if the array index is outside the array bounds. The array bounds are located in memory at a location indicated by one of the instruction operands. The other operand indicates the value of the index to be checked.

UNUSED OPCODE EXCEPTION (TYPE 6)

Generated if execution is attempted on undefined opcodes.

ESCAPE OPCODE EXCEPTION (TYPE 7)

Generated if execution is attempted of ESC opcodes (D8H–DFH). The 80C188 does not check an escape opcode trap bit as does the 80C186. On the 80C188, ESC traps occcur in both compatible and enhanced operating modes. The return address of this exception will point to the ESC instruction causing the exception. If a segment override prefix preceded the ESC instruction, the return address will point to the segment override prefix.

NOTE:
Unlike the 80188, all numerics coprocessor opcodes cause a trap. The 80C188 does not support the numerics interface.

Hardware-generated interrupts are divided into two groups: maskable interrupts and non-maskable interrupts. The 80C188 provides maskable hardware interrupt request pins INT0–INT3. In addition, maskable interrupts may be generated by the 80C188 integrated DMA controller and the integrated timer unit. The vector types for these interrupts is shown in Table 4. Software enables these inputs by setting the interrupt flag bit (IF) in the Status Word. The interrupt controller is discussed in the peripheral section of this data sheet.

Further maskable interrupts are disabled while servicing an interrupt because the IF bit is reset as part of the response to an interrupt or exception. The saved Status Word will reflect the enable status of the processor prior to the interrupt. The interrupt flag will remain zero unless specifically set. The interrupt return instruction restores the Status Word, thereby restoring the original status of IF bit. If the interrupt return re-enables interrupts, and another interrupt is pending, the 80C188 will immediately service the highest-priority interrupt pending, i.e., no instructions of the main line program will be executed.

Initialization and Processor Reset

Processor initialization is accomplished by driving the $\overline{RES}$ input pin LOW. $\overline{RES}$ must be LOW during power-up to ensure proper device initialization. $\overline{RES}$ forces the 80C188 to terminate all execution and local bus activity. No instruction or bus activity will occur as long as $\overline{RES}$ is active. After $\overline{RES}$ becomes inactive and an internal processing interval elapses, the 80C188 begins execution with the instruction at physical location FFFF0(H). $\overline{RES}$ also sets some registers to predefined values as shown in Table 5.

Table 5. 80C188 Initial Register State after RESET

Status Word	F002(H)
Instruction Pointer	0000(H)
Code Segment	FFFF(H)
Data Segment	0000(H)
Extra Segment	0000(H)
Stack Segment	0000(H)
Relocation Register	20FF(H)
UMCS	FFFB(H)

THE 80C188 COMPARED TO THE 80C186

The 80C188 is an 8-bit processor designed based on the 80C186 internal structure. Most internal functions of the 80C188 are identical to the equivalent 80C186 functions. The 80C188 handles the external bus the same way the 80C186 does with the distinction of handling only 8 bits at a time. Sixteen-bit operands are fetched or written in two consecutive bus cycles. The processors will look the same to the software engineer, with the exception of execution time. The internal register structure is identical and all instructions except numerics instructions have the same end result. Internally, there are four differences between the 80C188 and the 80C186. All changes are related to the 8-bit bus interface.

- The queue length is 4 bytes in the 80C188, whereas the 80C186 queue contains 6 bytes, or three words. The queue was shortened to prevent overuse of the bus by the BIU when prefetching instructions. This was required because of the additional time necessary to fetch instructions 8 bits at a time.
- To further optimize the queue, the prefetching algorithm was changed. The 80C188 BIU will fetch a new instruction to load into the queue each time there is a 1-byte hole (space available) in the queue. The 80C186 waits until a 2-byte space is available.
- The internal execution time of an instruction is affected by the 8-bit interface. All 16-bit fetches and writes from/to memory take an additional four clock cycles. The CPU may also be limited by the rate of instruction fetches when a series of simple operations occur. When the more sophisticated instructions of the 80C188 are being used, the queue has more time to fill and the execution proceeds more closely to the speed at which the execution unit will allow.
- The 80C188 does not have a numerics interface, since the 80C186 numerics interface inherently requires 16-bit communication with the numerics coprocessor.

The 80C188 and 80C186 are completely software compatible (except for numerics instructions) by virtue of their identical execution units. However, software that is system dependent may not be completely transferable.

The bus interface and associated control signals vary somewhat between the two processors. The pin assignments are nearly identical, with the following functional changes:

- A8–A15—These pins are only address outputs on the 80C188. These address lines are latched internally and remain valid throughout the bus cycle.
- $\overline{BHE}$ has no meaning on the 80C188. However, it was necessary to designate this pin the $\overline{RFSH}$ pin in order to provide an indication of DRAM refresh bus cycles.

80C188 CLOCK GENERATOR

The 80C188 provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, synchronous and asynchronous ready inputs, and reset circuitry.

Oscillator

The 80C188 oscillator circuit is designed to be used either with a parallel resonant fundamental or third-overtone mode crystal, depending upon the frequency range of the application as shown in Figure 8c. This is used as the time base for the 80C188. The crystal frequency chosen should be twice the required processor frequency. Use of an LC or RC circuit is not recommended.

The output of the oscillator is not directly available outside the 80C188. The two recommended crystal configurations are shown in Figures 8a and 8b. When used in third-overtone mode the tank circuit shown in Figure 8b is recommended for stable operation. The sum of the stray capacitances and loading capacitors should equal the values shown. It is advisable to limit stray capacitance between the X1 and X2 pins to less than 10 pF. While a fundamental-mode circuit will require approximately 1 ms for start-up, the third-overtone arrangement may require 1 ms to 3 ms to stabilize.

Alternately, the oscillator may be driven from an external source as shown in Figure 8d. The configuration shown in Figure 8e is not recommended.

Intel recommends the following values for crystal selection parameters:

Temperature Range:	0 to 70°C
ESR (Equivalent Series Resistance):	40Ω max
C_0 (Shunt Capacitance of Crystal):	7.0 pF max
C_1 (Load Capacitance):	20 pF ± 2 pF
Drive Level:	1 mW max

Clock Generator

The 80C188 clock generator provides the 50% duty cycle processor clock for the 80C188. It does this by dividing the oscillator output by 2 forming the symmetrical clock. If an external oscillator is used, the state of the clock generator will change on the falling edge of the oscillator signal. The CLKOUT pin provides the processor clock signal for use outside the 80C188. This may be used to drive other system components. All timings are referenced to the output clock.

READY Synchronization

The 80C188 provides both synchronous and asynchronous ready inputs. Asynchronous ready synchronization is accomplished by circuitry which samples ARDY in the middle of T_2, T_3 and again in the middle of each T_W until ARDY is sampled HIGH. One-half CLKOUT cycle of resolution time is used for full synchronization of a rising ARDY signal. A high-to-low transition on ARDY may be used as an indication of the not ready condition but it must be performed synchronously to CLKOUT **either** in the middle of T_2, T_3 or T_W, **or** at the falling edge of T_3 or T_W.

A second ready input (SRDY) is provided to interface with externally synchronized ready signals. This input is sampled at the end of T_2, T_3 and again at the end of each T_W until it is sampled HIGH. By using this input rather than the asynchronous ready input, the half-clock cycle resolution time penalty is eliminated. This input must satisfy set-up and hold times to guarantee proper operation of the circuit.

In addition, the 80C188, as part of the integrated chip-select logic, has the capability to program WAIT states for memory and peripheral blocks. This is discussed in the Chip Select/Ready Logic description.

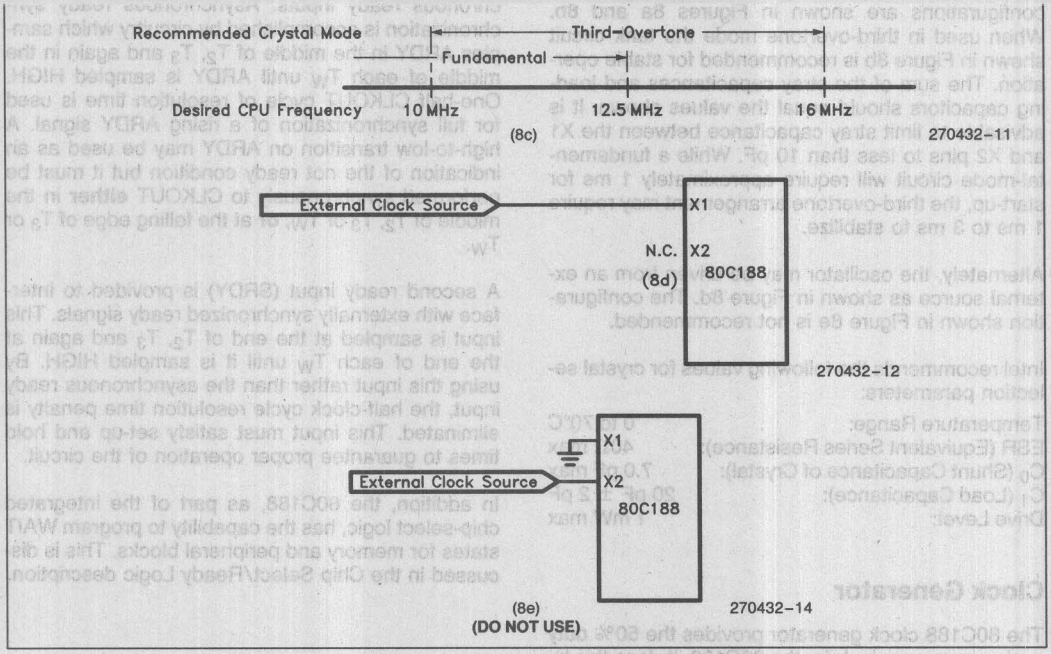


Figure 8. 80C188 Oscillator Configurations (see text)

The 80C188 provides a local bus controller to generate the local bus control signals. In addition, it employs a HOLD/HLDA protocol for relinquishing the local bus to other bus masters. It also provides outputs that can be used to enable external buffers and to direct the flow of data on and off the local bus.

Memory/Peripheral Control

The 80C188 provides ALE, $\overline{RD}$, and $\overline{WR}$ bus control signals. The $\overline{RD}$ and $\overline{WR}$ signals are used to strobe data from memory or I/O to the 80C188 or to strobe data from the 80C188 to memory or I/O. The ALE line provides a strobe to latch the address when it is valid. The 80C188 local bus controller does not provide a memory/$\overline{I/O}$ signal. If this is required, use the $\overline{S2}$ signal (which will require external latching), make the memory and I/O spaces nonoverlapping, or use only the integrated chip-select circuitry.

Transceiver Control

The 80C188 generates two control signals for external transceiver chips. This capability allows the addition of transceivers for extra buffering without adding external logic. These control lines, DT/$\overline{R}$ and $\overline{DEN}$, are generated to control the flow of data through the transceivers. The operation of these signals is shown in Table 6.

	while a LOW level directs data toward the processor during a read operation.

Local Bus Arbitration

The 80C188 uses a HOLD/HLDA system of local bus exchange. This provides an asynchronous bus exchange mechanism. This means multiple masters utilizing the same bus can operate at separate clock frequencies. The 80C188 provides a single HOLD/HLDA pair through which all other bus masters may gain control of the local bus. External circuitry must arbitrate which external device will gain control of the bus when there is more than one alternate local bus master. When the 80C188 relinquishes control of the local bus, it floats $\overline{DEN}$, $\overline{RD}$, $\overline{WR}$, $\overline{S0}$–$\overline{S2}$, $\overline{LOCK}$, AD0–AD7, A8–A19, S7/$\overline{RFSH}$, and DT/$\overline{R}$ to allow another master to drive these lines directly.

The 80C188 HOLD latency time, i.e., the time between HOLD request and HOLD acknowledge, is a function of the activity occurring in the processor when the HOLD request is received. A HOLD request is second only to DRAM refresh requests in priority of activity requests the processor may receive. Any bus cycle in progress will be completed before the 80C188 relinquishes the bus. This implies that if a HOLD request is received just as a DMA transfer begins, the HOLD latency can be as great as 4 bus cycles. This will occur if a DMA word transfer operation is taking place from an odd address to an odd address. This is a total of 16 clock cycles or more if WAIT states are required. In addition, if locked transfers are performed, the HOLD latency time will be increased by the length of the locked transfer.

If the 80C188 has relinquished the bus and a refresh request is pending, HLDA is removed (driven LOW) to signal the remote processor that the 80C188 wishes to regain control of the bus. The 80C188 will wait until HOLD is removed before taking control of the bus to run the refresh cycle.

Local Bus Controller and Reset

During RESET, the local bus controller will perform the following action:

- Drive $\overline{DEN}$, $\overline{RD}$, and $\overline{WR}$ HIGH for one clock cycle, then float them.
- Drive $\overline{S0}$–$\overline{S2}$ to the inactive state (all HIGH) and then float.
- Drive $\overline{LOCK}$ HIGH and then float.
- Float AD0–AD7, A8–A19, S7/$\overline{RFSH}$, DT/$\overline{R}$.
- Drive ALE LOW.
- Drive HLDA LOW.

$\overline{RD}$/$\overline{QSMD}$, $\overline{UCS}$, $\overline{LCS}$, and $\overline{TEST}$ pins have internal pullup devices which are active while $\overline{RES}$ is applied. Excessive loading or grounding certain of these pins causes the 80C188 to enter an alternative mode of operation:

- $\overline{RD}$/$\overline{QSMD}$ LOW results in Queue Status Mode.
- $\overline{UCS}$ and $\overline{LCS}$ LOW results in ONCE Mode.
- $\overline{TEST}$ LOW (and HIGH later) results in Enhanced Mode.

INTERNAL PERIPHERAL INTERFACE

All the 80C188 integrated peripherals are controlled by 16-bit registers contained within an internal 256-byte control block. The control block may be mapped into either memory or I/O space. Internal logic will recognize control block addresses and respond to bus cycles. During bus cycles to internal registers, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle), but D_{15-0}, SRDY, and ARDY will be ignored. The base address of the control block must be on an even 256-byte boundary (i.e., the lower 8 bits of the base address are all zeros). All of the defined registers within this control block may be read or written by the 80C188 CPU at any time.

The control block base address is programmed by a 16-bit relocation register contained within the control block at offset FEH from the base address of the control block (see Figure 9). It provides the upper 12 bits of the base address of the control block. The control block is effectively an internal chip select range and must abide by all the rules concerning chip selects (the chip select circuitry is discussed later in this data sheet). Any access to the 256 bytes of the control block activates an internal chip select. Other chip selects may overlap the control block only if they are programmed to zero wait states and ignore external ready. In addition, bit 12 of this register determines whether the control block will be mapped into I/O or memory space. If this bit is 1, the control block will be located in memory space. If the bit is 0, the control block will be located in I/O space. If the control register block is mapped into I/O space, the upper 4 bits of the base address must be programmed as 0 (since I/O addresses are only 16 bits wide).

In addition to providing relocation information for the control block, the relocation register contains bits which place the interrupt controller into Slave Mode. At RESET, the relocation register is set to 20FFH, which maps the control block to start at FF00H in I/O space. An offset map of the 256-byte control register block is shown in Figure 10.

CHIP-SELECT/READY GENERATION LOGIC

The 80C188 contains logic which provides programmable chip-select generation for both memories and peripherals. In addition, it can be programmed to provide READY (or WAIT state) generation. It can also provide latched address bits A1 and A2. The chip-select lines are active for all memory and I/O cycles in their programmed areas, whether they be generated by the CPU or by the integrated DMA unit.

Memory Chip Selects

The 80C188 provides 6 memory chip select outputs for 3 address areas; upper memory, lower memory, and midrange memory. One each is provided for upper memory and lower memory, while four are provided for midrange memory.

The range for each chip select is user-programmable and can be set to 2K, 4K, 8K, 16K, 32K, 64K, 128K (plus 1K and 256K for upper and lower chip selects). In addition, the beginning or base address of the midrange memory chip select may also be selected. Only one chip select may be programmed to be active for any memory location at a time. All chip select sizes are in bytes.

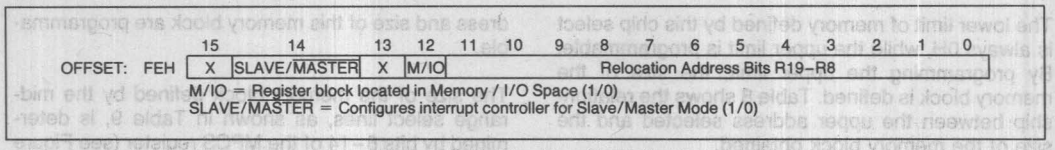


Figure 9. Relocation Register

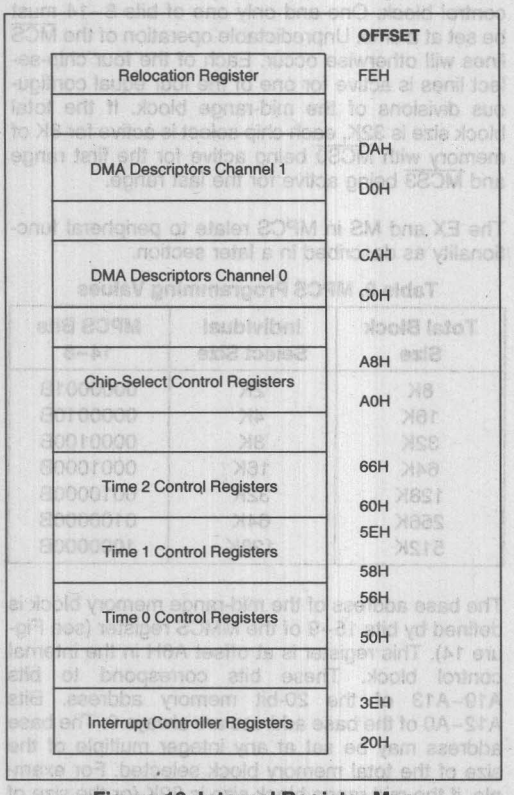


Figure 10. Internal Register Map

Upper Memory $\overline{CS}$

The 80C188 provides a chip select, called $\overline{UCS}$, for the top of memory. The top of memory is usually used as the system memory because after reset the 80C188 begins executing at memory location FFFF0H.

The upper limit of memory defined by this chip select is always FFFFFH, while the lower limit is programmable. By programming the lower limit, the size of the select block is also defined. Table 7 shows the relationship between the base address selected and the size of the memory block obtained.

Table 7. UMCS Programming Values

Starting Address (Base Address)	Memory Block Size	UMCS Value (Assuming R0 = R1 = R2 = 0)
FFC00	1K	FFF8H
FF800	2K	FFB8H
FF000	4K	FF38H
FE000	8K	FE38H
FC000	16K	FC38H
F8000	32K	F838H
F0000	64K	F038H
E0000	128K	E038H
C0000	256K	C038H

The lower limit of this memory block is defined in the UMCS register (see Figure 11). This register is at offset A0H in the internal control block. The legal values for bits 6–13 and the resulting starting address and memory block sizes are given in Table 7. Any combination of bits 6–13 not shown in Table 7 will result in undefined operation. After reset, the UMCS register is programmed for a 1K area. It must be reprogrammed if a larger upper memory area is desired.

The internal generation of any 20-bit address whose upper 16 bits are equal to or greater than the UMCS value (with bits 0–5 as "0") asserts $\overline{UCS}$. UMCS bits R2–R0 specify the ready mode for the area of memory defined by the chip select register, as explained later.

Lower Memory $\overline{CS}$

The 80C188 provides a chip select for low memory called $\overline{LCS}$. The bottom of memory contains the interrupt vector table, starting at location 00000H.

The lower limit of memory defined by this chip select is always 0H, while the upper limit is programmable. By programming the upper limit, the size of the memory block is defined. Table 8 shows the relationship between the upper address selected and the size of the memory block obtained.

Table 8. LMCS Programming Values

Upper Address	Memory Block Size	LMCS Value (Assuming R0=R1=R2=0)
003FFH	1K	0038H
007FFH	2K	0078H
00FFFH	4K	00F8H
01FFFH	8K	01F8H
03FFFH	16K	03F8H
07FFFH	32K	07F8H
0FFFFH	64K	0FF8H
1FFFFH	128K	1FF8H
3FFFFH	256K	3FF8H

The upper limit of this memory block is defined in the LMCS register (see Figure 12) at offset A2H in the internal control block. The legal values for bits 6–15 and the resulting upper address and memory block sizes are given in Table 8. Any combination of bits 6–15 not shown in Table 8 will result in undefined operation. After RESET, the LMCS register value is undefined. However, the $\overline{LCS}$ chip-select line will not become active until the LMCS register is accessed.

Any internally generated 20-bit address whose upper 16 bits are less than or equal to LMCS (with bits 0–5 "1") will assert $\overline{LCS}$. LMCS register bits R2–R0 specify the READY mode for the area of memory defined by this chip-select register.

Mid-Range Memory $\overline{CS}$

The 80C188 provides four $\overline{MCS}$ lines which are active within a user-locatable memory block. This block can be located within the 80C188 1M byte memory address space exclusive of the areas defined by $\overline{UCS}$ and $\overline{LCS}$. Both the base address and size of this memory block are programmable.

The size of the memory block defined by the mid-range select lines, as shown in Table 9, is determined by bits 8–14 of the MPCS register (see Figure 13). This register is at location A8H in the internal control block. One and only one of bits 8–14 must be set at a time. Unpredictable operation of the $\overline{MCS}$ lines will otherwise occur. Each of the four chip-select lines is active for one of the four equal contiguous divisions of the mid-range block. If the total block size is 32K, each chip select is active for 8K of memory with $\overline{MCS0}$ being active for the first range and $\overline{MCS3}$ being active for the last range.

The EX and MS in MPCS relate to peripheral functionality as described in a later section.

Table 9. MPCS Programming Values

Total Block Size	Individual Select Size	MPCS Bits 14–8
8K	2K	0000001B
16K	4K	0000010B
32K	8K	0000100B
64K	16K	0001000B
128K	32K	0010000B
256K	64K	0100000B
512K	128K	1000000B

The base address of the mid-range memory block is defined by bits 15–9 of the MMCS register (see Figure 14). This register is at offset A6H in the internal control block. These bits correspond to bits A19–A13 of the 20-bit memory address. Bits A12–A0 of the base address are always 0. The base address may be set at any integer multiple of the size of the total memory block selected. For example, if the mid-range block size is 32K (or the size of the block for which each $\overline{MCS}$ line is active is 8K), the block could be located at 10000H or 18000H, but not at 14000H, since the first few integer multiples of a 32K memory block are 0H, 8000H, 10000H, 18000H, etc. After RESET, the contents of both registers are undefined. However, none of the $\overline{MCS}$ lines will be active until both the MMCS and MPCS registers are accessed.

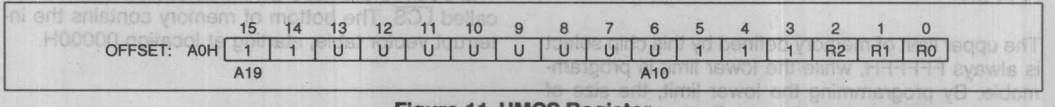


Figure 11. UMCS Register

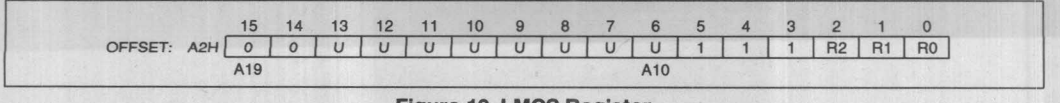


Figure 12. LMCS Register

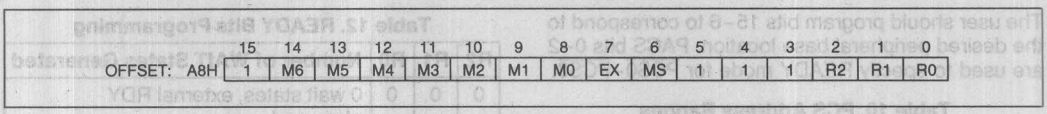


Figure 13. MPCS Register

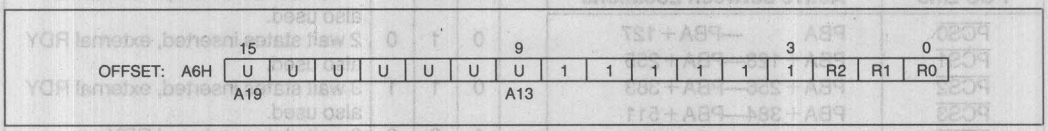


Figure 14. MMCS Register

MMCS bits R2–R0 specify READY mode of operation for all four mid-range chip selects.

The 512K block size for the mid-range memory chip selects is a special case. When using 512K, the base address would have to be at either locations 00000H or 80000H. If it were to be programmed at 00000H when the $\overline{LCS}$ line was programmed, there would be an internal conflict between the $\overline{LCS}$ ready generation logic and the $\overline{MCS}$ ready generation logic. Likewise, if the base address were programmed at 80000H, there would be a conflict with the $\overline{UCS}$ ready generation logic. Since the $\overline{LCS}$ chip-select line does not become active until programmed, while the $\overline{UCS}$ line is active at reset, the memory base can be set only at 00000H. If this base address is selected, however, the $\overline{LCS}$ range must not be programmed.

Peripheral Chip Selects

The 80C188 can generate chip selects for up to seven peripheral devices. These chip selects are active for seven contiguous blocks of 128 bytes above a programmable base address. The base address may be located in either memory or I/O space.

Seven $\overline{CS}$ lines called $\overline{PCS0}$–6 are generated by the 80C188. The base address is user-programmable; however it can only be a multiple of 1K bytes, i.e., the least significant 10 bits of the starting address are always 0.

$\overline{PCS5}$ and $\overline{PCS6}$ can also be programmed to provide latched address bits A1 and A2. If so programmed, they cannot be used as peripheral selects. These outputs can be connected directly to the A0 and A1 pins used for selecting internal registers of 8-bit peripheral chips.

The starting address of the peripheral chip-select block is defined by the PACS register (see Figure 15). The register is located at offset A4H in the internal control block. Bits 15–6 of this register correspond to bits 19–10 of the 20-bit Programmable Base Address (PBA) of the peripheral chip-select block. Bits 9–0 of the PBA of the peripheral chip-select block are all zeros. If the chip-select block is located in I/O space, bits 12–15 must be programmed zero, since the I/O address is only 16 bits wide. Table 10 shows the address range of each peripheral chip select with respect to the PBA contained in PACS register.

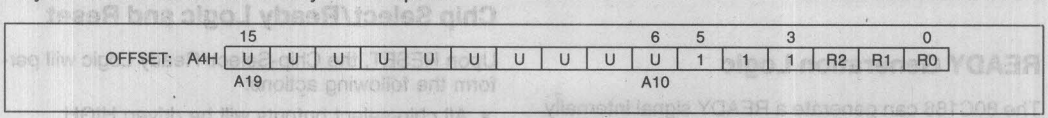


Figure 15. PACS Register

The user should program bits 15–6 to correspond to the desired peripheral base location. PACS bits 0–2 are used to specify READY mode for $\overline{PCS0}$–$\overline{PCS3}$.

Table 10. PCS Address Ranges

$\overline{PCS}$ Line	Active between Locations
$\overline{PCS0}$	PBA —PBA + 127
$\overline{PCS1}$	PBA + 128—PBA + 255
$\overline{PCS2}$	PBA + 256—PBA + 383
$\overline{PCS3}$	PBA + 384—PBA + 511
$\overline{PCS4}$	PBA + 512—PBA + 639
$\overline{PCS5}$	PBA + 640—PBA + 767
$\overline{PCS6}$	PBA + 768—PBA + 895

The mode of operation of the peripheral chip selects is defined by the MPCS register (which is also used to set the size of the mid-range memory chip-select block, see Figure 13). The register is located at offset A8H in the internal control block. Bit 7 is used to select the function of $\overline{PCS5}$ and $\overline{PCS6}$, while bit 6 is used to select whether the peripheral chip selects are mapped into memory or I/O space. Table 11 describes the programming of these bits. After RESET, the contents of both the MPCS and the PACS registers are undefined, however none of the PCS lines will be active until both of the MPCS and PACS registers are accessed.

Table 11. MS, EX Programming Values

Bit	Description
MS	1 = Peripherals mapped into memory space.
	0 = Peripherals mapped into I/O space.
EX	0 = 5 $\overline{PCS}$ lines. A1, A2 provided.
	1 = 7 $\overline{PCS}$ lines. A1, A2 are not provided.

MPCS bits 0–2 specify the READY mode for $\overline{PCS4}$–$\overline{PCS6}$ as outlined below.

READY Generation Logic

The 80C188 can generate a READY signal internally for each of the memory or peripheral $\overline{CS}$ lines. The number of WAIT states to be inserted for each peripheral or memory is programmable to provide 0–3 wait states for all accesses to the area for which the chip select is active. In addition, the 80C188 may be programmed to either ignore external READY for each chip-select range individually or to factor external READY with the integrated ready generator.

READY control consists of 3 bits for each $\overline{CS}$ line or group of lines generated by the 80C188. The interpretation of the READY bits is shown in Table 12.

Table 12. READY Bits Programming

R2	R1	R0	Number of WAIT States Generated
0	0	0	0 wait states, external RDY also used.
0	0	1	1 wait state inserted, external RDY also used.
0	1	0	2 wait states inserted, external RDY also used.
0	1	1	3 wait states inserted, external RDY also used.
1	0	0	0 wait states, external RDY ignored.
1	0	1	1 wait state inserted, external RDY ignored.
1	1	0	2 wait states inserted, external RDY ignored.
1	1	1	3 wait states inserted, external RDY ignored.

The internal READY generator operates in parallel with external READY, not in series, if the external READY is used (R2 = 0). For example, if the internal generator is set to insert two wait states, but activity on the external READY lines will insert four wait states, the processor will only insert four wait states, not six. This is because the two wait states generated by the internal generator overlapped the first two wait states generated by the external ready signal. Note that the external ARDY and SRDY lines are always ignored during cycles accessing internal peripherals.

R2–R0 of each control word specifies the READY mode for the corresponding block, with the exception of the peripheral chip selects: R2–R0 of PACS set the $\overline{PCS0}$–3 READY mode, R2–R0 of MPCS set the $\overline{PCS4}$–6 READY mode.

Chip Select/Ready Logic and Reset

Upon RESET, the Chip-Select/Ready Logic will perform the following actions:

- All chip-select outputs will be driven HIGH.
- Upon leaving RESET, the $\overline{UCS}$ line will be programmed to provide chip selects to a 1K block with the accompanying READY control bits set at 011 to insert 3 wait states in conjunction with external READY (i.e., UMCS resets to FFFBH).
- No other chip select or READY control registers have any predefined values after RESET. They will not become active until the CPU accesses their control registers. Both the PACS and MPCS registers must be accessed before the $\overline{PCS}$ lines will become active.

DMA CHANNELS

The 80C188 DMA controller provides two independent DMA channels. Data transfers can occur between memory and I/O spaces (e.g., Memory to I/O) or within the same space (e.g., Memory to Memory or I/O to I/O). Each DMA channel maintains both a 20-bit source and destination pointer which can be optionally incremented or decremented after each data transfer. Each data transfer consumes 2 bus cycles (a minimum of 8 clocks), one cycle to fetch data and the other to store data.

DMA Operation

Each channel has six registers in the control block which define each channel's operation. The control registers consist of a 20-bit Source pointer (2 words), a 20-bit destination pointer (2 words), a 16-bit Transfer Count Register, and a 16-bit Control Word. The format of the DMA Control Blocks is shown in Table 13. The Transfer Count Register (TC) specifies the number of DMA transfers to be performed. Up to 64K byte transfers can be performed with automatic termination. The Control Word defines the channel's operation (see Figure 17). All registers may be modified or altered during any DMA activity. Any changes made to these registers will be reflected immediately in DMA operation.

Table 13. DMA Control Block Format

Register Name	Register Address	
	Ch. 0	Ch. 1
Control Word	CAH	DAH
Transfer Count	C8H	D8H
Destination Pointer (upper 4 bits)	C6H	D6H
Destination Pointer	C4H	D4H
Source Pointer (upper 4 bits)	C2H	D2H
Source Pointer	C0H	D0H

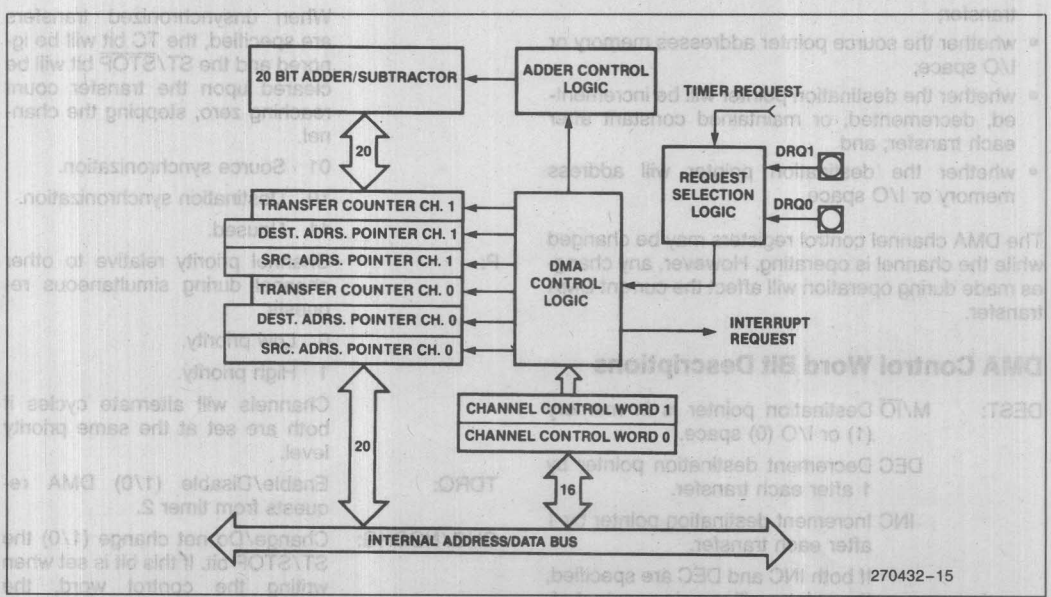


Figure 16. DMA Unit Block Diagram

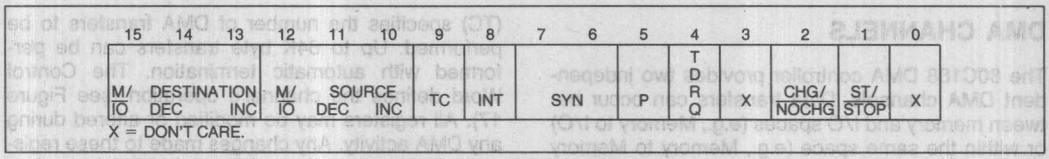


Figure 17. DMA Control Register

DMA Channel Control Word Register

Each DMA Channel Control Word determines the mode of operation for the particular 80C188 DMA channel. This register specifies:

- the mode of synchronization;
- whether interrupts will be generated after the last transfer;
- whether DMA activity will cease after a programmed number of DMA cycles;
- the relative priority of the DMA channel with respect to the other DMA channel;
- whether the source pointer will be incremented, decremented, or maintained constant after each transfer;
- whether the source pointer addresses memory or I/O space;
- whether the destination pointer will be incremented, decremented, or maintained constant after each transfer; and
- whether the destination pointer will address memory or I/O space.

The DMA channel control registers may be changed while the channel is operating. However, any changes made during operation will affect the current DMA transfer.

DMA Control Word Bit Descriptions

DEST: M/$\overline{IO}$ Destination pointer is in memory (1) or I/O (0) space.

DEC Decrement destination pointer by 1 after each transfer.

INC Increment destination pointer by 1 after each transfer.

If both INC and DEC are specified, the pointer will remain constant after each cycle.

SOURCE: M/$\overline{IO}$ Source pointer is in memory (1) or I/O (0) space.

DEC Decrement source pointer by 1 after each transfer.

INC Increment source pointer by 1 after each transfer.

If both INC and DEC are specified, the pointer will remain constant after each cycle.

TC: If set, DMA will terminate when the contents of the transfer count register reach zero. The ST/$\overline{STOP}$ bit will also be reset at this point. If cleared, the DMA controller will decrement the transfer count register for each DMA cycle, but the DMA transfers will not stop when the transfer count register reaches zero.

INT: Enable interrupts to CPU upon transfer count termination.

SYN: 00 No synchronization.

NOTE:

When unsynchronized transfers are specified, the TC bit will be ignored and the ST/$\overline{STOP}$ bit will be cleared upon the transfer count reaching zero, stopping the channel.

01 Source synchronization.

10 Destination synchronization.

11 Unused.

P: Channel priority relative to other channel during simultaneous requests.

0 Low priority.

1 High priority.

Channels will alternate cycles if both are set at the same priority level.

TDRQ: Enable/Disable (1/0) DMA requests from timer 2.

CHG/$\overline{NOCHG}$: Change/Do not change (1/0) the ST/$\overline{STOP}$ bit. If this bit is set when writing the control word, the ST/$\overline{STOP}$ bit will be programmed by the write to the control word. If this bit is cleared when writing the control word, the ST/$\overline{STOP}$ bit will not be altered. This bit is not stored; it will always be read as 0.

ST/$\overline{STOP}$: Start/Stop (1/0) channel.

DMA Destination and Source Pointer Registers

Each DMA channel maintains a 20-bit source and a 20-bit destination pointer. Each of these pointers takes up two full 16-bit registers in the peripheral control block. For each DMA Channel to be used, all four pointer registers must be initialized. The lower four bits of the upper register contain the upper four bits of the 20-bit physical address (see Figure 18). These pointers may be individually incremented or decremented after each transfer.

Each pointer may point into either memory or I/O space. Since the upper four bits of the address are not automatically programmed to zero, the user must program them in order to address the normal 64K I/O space. There is no restriction on values for the pointer registers.

DMA Transfer Count Register

Each DMA channel maintains a 16-bit transfer count register (TC). The register is decremented after every DMA cycle, regardless of the state of the TC bit in the DMA Control Register. If the TC bit in the DMA control word is set or if unsynchronized transfers are programmed, however, DMA activity will terminate when the transfer count register reaches zero.

DMA Requests

Data transfers may be either source or destination synchronized, that is either the source of the data or the destination of the data may request the data transfer. In addition, DMA transfers may be unsynchronized; that is, the transfer will take place continually until the correct number of transfers has occurred. When source or unsynchronized transfers are performed, the DMA channel may begin another transfer immediately after the end of a previous DMA transfer. This allows a complete transfer to take place every 2 bus cycles or eight clock cycles (assuming no wait states). When destination synchronization is performed, data will not be fetched from the source address until the destination device signals that it is ready to receive it. Also, the DMA controller will relinquish control of the bus after every transfer. If no other bus activity is initiated, another destination synchronized DMA cycle will begin after two processor clocks. This allows the destination device time to remove its request if another transfer is not desired. Since the DMA controller will relinquish the bus, the CPU can initiate a bus cycle. As a result, a complete bus cycle will often be inserted between destination synchronized transfers. Table 14 shows the maximum DMA transfer rates.

Table 14. Maximum DMA Transfer Rates at CLKOUT = 16 MHz

Type of Synchronization Selected	CPU Running	CPU Halted
Unsynchronized	2.0 MBytes/sec	2.0 MBytes/sec
Source Synch	2.0 MBytes/sec	2.0 MBytes/sec
Destination Synch	1.3 MBytes/sec	1.6 MBytes/sec

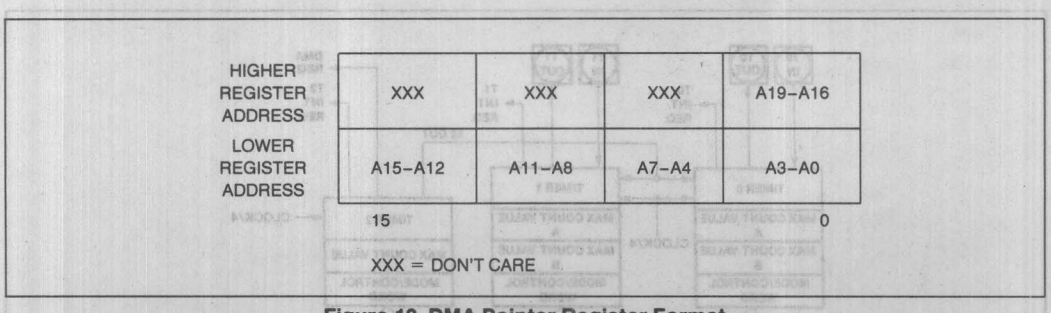


Figure 18. DMA Pointer Register Format

DMA Acknowledge

No explicit DMA acknowledge pulse is provided. Since both source and destination pointers are maintained, a read from a requesting source, or a write to a requesting destination, should be used as the DMA acknowledge signal. Since the chip-select lines can be programmed to be active for a given block of memory or I/O space, and the DMA pointers can be programmed to point to the same given block, a chip-select line could be used to indicate a DMA acknowledge.

DMA Priority

The DMA channels may be programmed to give one channel priority over the other, or they may be programmed to alternate cycles when both have DMA requests pending. DMA cycles always have priority over internal CPU cycles except between locked memory accesses; also, an external bus hold takes priority over an internal DMA cycle. Because an interrupt request cannot suspend a DMA operation and the CPU cannot access memory during a DMA cycle, interrupt latency time will suffer during sequences of continuous DMA cycles. An NMI request, however, will cause all internal DMA activity to halt. This allows the CPU to quickly respond to the NMI request.

DMA Programming

DMA cycles will occur whenever the ST/$\overline{\text{STOP}}$ bit of the Control Register is set. If synchronized transfers are programmed, a DRQ must also be generated. Therefore the source and destination transfer pointers, and the transfer count register (if used) must be programmed before the ST/STOP bit is set.

Each DMA register may be modified while the channel is operating. If the CHG/NOCHG bit is cleared when the control register is written, the ST/STOP bit of the control register will not be modified by the write. If multiple channel registers are modified, it is recommended that a LOCKED string transfer be used to prevent a DMA transfer from occurring between updates to the channel registers.

DMA Channels and Reset

Upon RESET, the state of the DMA channels will be as follows:

- The ST/$\overline{\text{STOP}}$ bit for each channel will be reset to $\overline{\text{STOP}}$.
- Any transfer in progress is aborted.
- The values of the transfer count registers, source pointers and destination pointers are indeterminate.

TIMERS

The 80C188 provides three internal 16-bit programmable timers (see Figure 19). Two of these are highly flexible and are connected to four external pins (2 per timer). They can be used to count external events, time external events, generate nonrepetitive waveforms, etc. The third timer is not connected to any external pins, and is useful for real-time coding and time delay applications. In addition, the third timer can be used as a prescaler to the other two, or as a DMA request source.

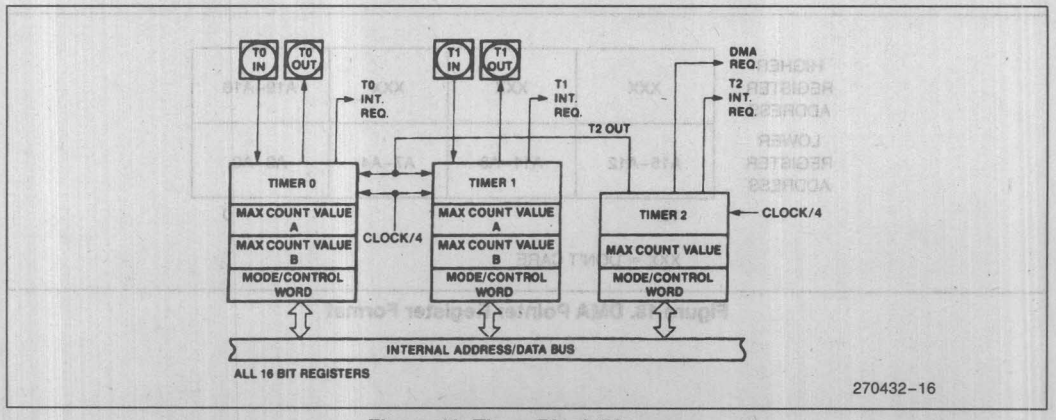


Figure 19. Timer Block Diagram

Timer Operation

The timers are controlled by 11 16-bit registers in the peripheral control block. The configuration of these registers is shown in Table 15. The count register contains the current value of the timer. It can be read or written at any time independent of whether the timer is running or not. The value of this register will be incremented for each timer event. Each of the timers is equipped with a MAX COUNT register, which defines the maximum count the timer will reach. After reaching the MAX COUNT register value, the timer count value will reset to zero during that same clock, i.e., the maximum count value is never stored in the count register itself. Timers 0 and 1 are, in addition, equipped with a second MAX COUNT register, which enables the timers to alternate their count between two different MAX COUNT values. If a single MAX COUNT register is used, the timer output pin will switch LOW for a single clock, 1 clock after the maximum count value has been reached. In the dual MAX COUNT register mode, the output pin will indicate which MAX COUNT register is currently in use, thus allowing nearly complete freedom in selecting waveform duty cycles. For the timers with two MAX COUNT registers, the RIU bit in the control register determines which is used for the comparison.

Each timer gets serviced every fourth CPU-clock cycle, and thus can operate at speeds up to one-quarter the internal clock frequency (one-eighth the crystal rate). External clocking of the timers may be done at up to a rate of one-quarter of the internal CPU-clock rate. Due to internal synchronization and pipelining of the timer circuitry, a timer output may take up to 6 clocks to respond to any individual clock or gate input.

Since the count registers and the maximum count registers are all 16 bits wide, 16 bits of resolution are provided. Any Read or Write access to the timers will add one wait state to the minimum four-clock bus cycle, however. This is needed to synchronize and coordinate the internal data flows between the internal timers and the internal bus.

The timers have several programmable options.

- All three timers can be set to halt or continue on a terminal count.
- Timers 0 and 1 can select between internal and external clocks, alternate between MAX COUNT registers and be set to retrigger on external events.
- The timers may be programmed to cause an interrupt on terminal count.

These options are selectable via the timer mode/control word.

Timer Mode/Control Register

The mode/control register (see Figure 20) allows the user to program the specific mode of operation or check the current programmed status for any of the three integrated timers.

Table 15. Timer Control Block Format

Register Name	Register Offset		
	Tmr. 0	Tmr. 1	Tmr. 2
Mode/Control Word	56H	5EH	66H
Max Count B	54H	5CH	not present
Max Count A	52H	5AH	62H
Count Register	50H	58H	60H

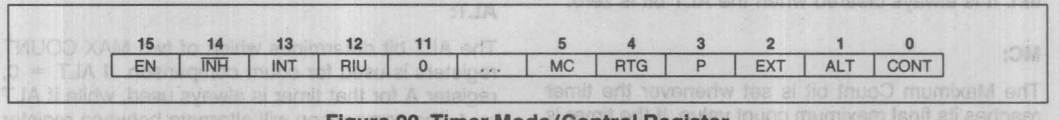


Figure 20. Timer Mode/Control Register

EN:

The enable bit provides programmer control over the timer's RUN/HALT status. When set, the timer is enabled to increment subject to the input pin constraints in the internal clock mode (discussed previously). When cleared, the timer will be inhibited from counting. All input pin transistions during the time EN is zero will be ignored. If CONT is zero, the EN bit is automatically cleared upon maximum count.

$\overline{\text{INH}}$:

The inhibit bit allows for selective updating of the enable (EN) bit. If $\overline{\text{INH}}$ is a one during the write to the mode/control word, then the state of the EN bit will be modified by the write. If $\overline{\text{INH}}$ is a zero during the write, the EN bit will be unaffected by the operation. This bit is not stored; it will always be a 0 on a read.

INT:

When set, the INT bit enables interrupts from the timer, which will be generated on every terminal count. If the timer is configured in dual MAX CONT register mode, an interrupt will be generated each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. If this enable bit is cleared after the interrupt request has been generated, but before a pending interrupt is serviced, the interrupt request will still be in force. (The request is latched in the Interrupt Controller).

RIU:

The Register In Use bit indicates which MAX COUNT register is currently being used for comparison to the timer count value. A zero value indicates register A. The RIU bit cannot be written, i.e., its value is not affected when the control register is written. It is always cleared when the ALT bit is zero.

MC:

The Maximum Count bit is set whenever the timer reaches its final maximum count value. If the timer is configured in dual MAX COUNT register mode, this bit will be set each time the value in MAX COUNT register A is reached, and each time the value in MAX COUNT register B is reached. This bit is set regardless of the timer's interrupt-enable bit. The MC bit gives the user the ability to monitor timer status through software instead of through interrupts.

Programmer intervention is required to clear this bit.

RTG:

Retrigger bit is only active for internal clocking (EXT = 0). In this case it determines the control function provided by the input pin.

If RTG = 0, the input level gates the internal clock on and off. If the input pin is HIGH, the timer will count; if the input pin is LOW, the timer will hold its value. As indicated previously, the input signal may be asynchronous with respect to the 80C188 clock.

When RTG = 1, the input pin detects LOW-to-HIGH transitions. The first such transition starts the timer running, clearing the timer value to zero on the first clock, and then incrementing thereafter. Further transitions on the input pin will again reset the timer to zero, from which it will start counting up again. If CONT = 0, when the timer has reached maximum count, the EN bit will be cleared, inhibiting further timer activity.

P:

The prescaler bit is ignored unless internal clocking has been selected (EXT = 0). If the P bit is a zero, the timer will count at one-fourth the internal CPU clock rate. If the P bit is a one, the output of timer 2 will be used as a clock for the timer. Note that the user must initialize and start timer 2 to obtain the prescaled clock.

EXT:

The external bit selects between internal and external clocking for the timer. The external signal may be asynchronous with respect to the 80C188 clock. If this bit is set, the timer will count LOW-to-HIGH transitions on the input pin. If cleared, it will count an internal clock while using the input pin for control. In this mode, the function of the external pin is defined by the RTG bit. The maximum input to output transition latency time may be as much as 6 clocks. However, clock inputs may be pipelined as closely together as every 4 clocks without losing clock pulses.

ALT:

The ALT bit determines which of two MAX COUNT registers is used for count comparison. If ALT = 0, register A for that timer is always used, while if ALT = 1, the comparison will alternate between register A and register B when each maximum count is reached. This alternation allows the user to change one MAX COUNT register while the other is being used, and thus provides a method of generating non-repetitive waveforms. Square waves and pulse outputs of any duty cycle are a subset of available signals obtained by not changing the final count registers. The ALT bit also determines the function of the timer output pin. If ALT is zero, the output pin will go LOW for one clock, the clock after the maximum count is reached. If ALT is one, the output pin will reflect the current MAX COUNT register being used (0/1 for B/A).

CONT:

Setting the CONT bit causes the associated timer to run continuously, while resetting it causes the timer to halt upon maximum count. If CONT = 0 and ALT = 1, the timer will count to the MAX COUNT register A value, reset, count to the register B value, reset, and halt.

Not all mode bits are provided for timer 2. Certain bits are hardwired as indicated below:

ALT = 0, EXT = 0, P = 0, RTG = 0, RIU = 0

Count Registers

Each of the three timers has a 16-bit count register. The contents of this register may be read or written by the processor at any time. If the register is written while the timer is counting,the new value will take effect in the current count cycle.

The count registers should be programmed before attempting to use the timers since they are not automatically initialized to zero.

Max Count Registers

Timers 0 and 1 have two MAX COUNT registers, while timer 2 has a single MAX COUNT register. These contain the number of events the timer will count. In timers 0 and 1, the MAX COUNT register used can alternate between the two max count values whenever the current maximum count is reached.

A timer resets when the timer count register equals the max count value being used. If the timer count register or the max count register is changed so that the max count is less than the timer count, the timer does not immediately reset. Instead, the timer counts up to 0FFFFH, "wraps around" to zero, counts up to the max count value, and then resets.

Timers and Reset

Upon RESET, the state of the timers will be as follows:

- All EN (Enable) bits are reset preventing timer counting.
- For Timers 0 and 1, the RIU bits are reset to zero and the ALT bits are set to one. This results in the Timer Out pins going HIGH.
- The contents of the count registers are indeterminate.

INTERRUPT CONTROLLER

The 80C188 can receive interrupts from a number of sources, both internal and external. The internal interrupt controller serves to merge these requests on a priority basis, for individual service by the CPU.

Internal interrupt sources (Timers and DMA channels) can be disabled by their own control registers or by mask bits within the interrupt controller. The 80C188 interrupt controller has its own control register that sets the mode of operation for the controller.

The interrupt controller will resolve priority among requests that are pending simultaneously. Nesting is provided so interrupt service routines for lower priority interrupts may be interrupted by higher priority interrupts. A block diagram of the interrupt controller is shown in Figure 21.

The 80C188 has a special Slave Mode in which the internal interrupt controller acts as a slave to an external master. The controller is programmed into this mode by setting bit 14 in the peripheral control block relocation register. (See Slave Mode section.)

MASTER MODE OPERATION

Interrupt Controller External Interface

Five pins are provided for external interrupt sources. One of these pins is NMI, the non-maskable interrupt. NMI is generally used for unusual events such as power-fail interrupts. The other four pins may be configured in any of the following ways:

- As four interrupt input lines with internally generated interrupt vectors.
- As an interrupt line and interrupt acknowledge line pair (cascade mode) with externally generated interrupt vectors plus two interrupt input lines with internally generated vectors.
- As two pairs of interrupt/interrupt acknowledge lines (Cascade Mode) with externally generated interrupt vectors.

External sources in the Cascade Mode use externally generated interrupt vectors. When an interrupt is acknowledged, two $\overline{\text{INTA}}$ cycles are initiated and the vector is read into the 80C188 on the second cycle. The capability to interface to external 82C59A programmable interrupt controllers is provided when the inputs are configured in Cascade Mode.

Interrupt Controller Modes of Operation

The basic modes of operation of the interrupt controller in master mode are similar to the 82C59A. The interrupt controller responds identically to internal interrupts in all three modes: the difference is only in the interpretation of function of the four external interrupt pins. The interrupt controller is set into one of these three modes by programming the correct bits in the INT0 and INT1 control registers. The modes of interrupt controller operation are as follows:

Fully Nested Mode

When in the fully nested mode four pins are used as direct interrupt requests as in Figure 22. The vectors for these four inputs are generated internally. An in-service bit is provided for every interrupt source. If a lower-priority device requests an interrupt while the in service bit (IS) is set, no interrupt will be generated by the interrupt controller. In addition, if another interrupt request occurs from the same interrupt source while the in-service bit is set, no interrupt will be generated by the interrupt controller. This allows interrupt service routines to operate with interrupts enabled, yet be suspended only by interrupts of higher priority than the in-service interrupt.

When a service routine is completed, the proper IS bit must be reset by writing the proper pattern to the EOI register. This is required to allow subsequent interrupts from this interrupt source and to allow servicing of lower-priority interrupts. An EOI command is executed at the end of the service routine just before the return from interrupt instruction. If the fully nested structure has been upheld, the next highest-priority source with its IS bit set is then serviced.

Cascade Mode

The 80C188 has four interrupt pins and two of them have dual functions. In the fully nested mode the four pins are used as direct interrupt inputs and the corresponding vectors are generated internally. In the Cascade Mode, the four pins are configured into interrupt input-dedicated acknowledge signal pairs. The interconnection is shown in Figure 23. INT0 is an interrupt input interfaced to an 82C59A, while INT2/$\overline{\text{INTA0}}$ serves as the dedicated interrupt acknowledge signal to that peripheral. The same is true for INT1 and INT3/$\overline{\text{INTA1}}$. Each pair can selectively be placed in the Cascade or non-Cascade Mode by programming the proper value into INT0 and INT1 control registers. The use of the dedicated acknowledge signals eliminates the need for the use of external logic to generate $\overline{\text{INTA}}$ and device select signals.

The primary Cascade Mode allows the capability to serve up to 128 external interrupt sources through the use of external master and slave 82C59As. Three levels of priority are created, requiring priority resolution in the 80C188 interrupt controller, the master 82C59As, and the slave 82C59As. If an external interrupt is serviced, one IS bit is set at each of these levels. When the interrupt service routine is completed, up to three end-of-interrupt commands must be issued by the programmer.

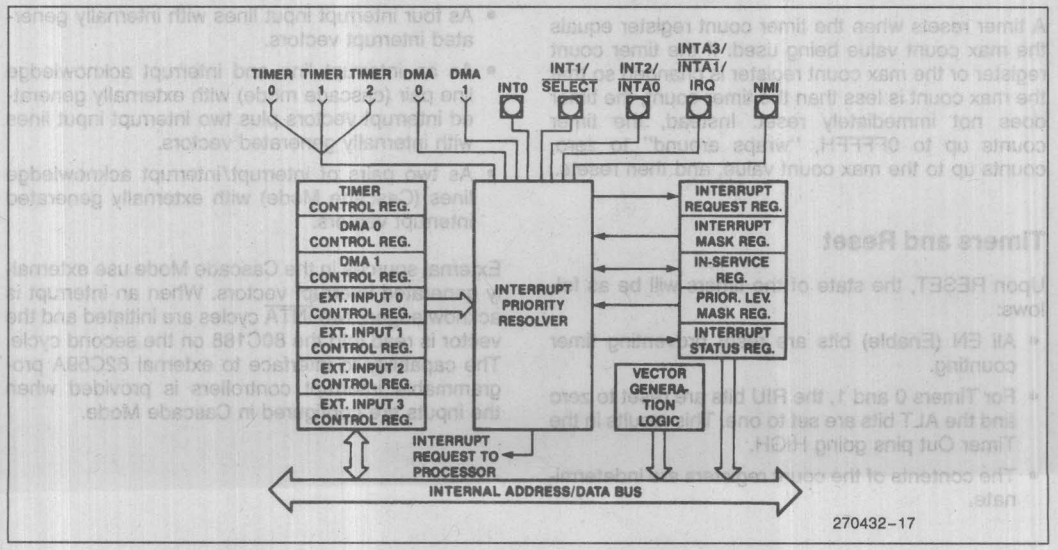


Figure 21. Interrupt Controller Block Diagram

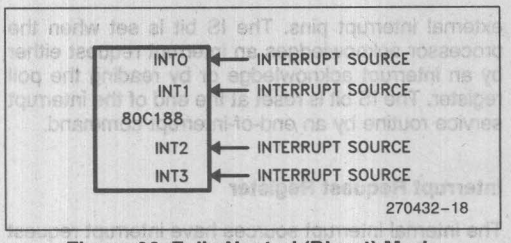


Figure 22. Fully Nested (Direct) Mode Interrupt Controller Connections

Special Fully Nested Mode

This mode is entered by setting the SFNM bit in INT0 or INT1 control register. It enables complete nestability with external 82C59A masters. Normally, an interrupt request from an interrupt source will not be recognized unless the in-service bit for that source is reset. If more than one interrupt source is connected to an external interrupt controller, all of the interrupts will be funneled through the same 80C188 interrupt request pin. As a result, if the external interrupt controller receives a higher-priority interrupt, its interrupt will not be recognized by the 80C188 controller until the 80C188 in-service bit is reset. In Special Fully Nested Mode, the 80C188 interrupt controller will allow interrupts from an external pin regardless of the state of the in-service bit for an interrupt source in order to allow multiple interrupts from a single pin. An in-service bit will continue to be set, however, to inhibit interrupts from other lower-priority 80C188 interrupt sources.

Special procedures should be followed when resetting IS bits at the end of interrupt service routines. Software polling of the IS register in the external master 82C59A is required to determine if there is more than one bit set. If so, the IS bit in the 80C188 remains active and the next interrupt service routine is entered.

Operation in a Polled Environment

The controller may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the interrupt controller whenever it is convenient. Polling the interrupt controller is accomplished by reading the Poll Word (Figure 32). Bit 15 in the poll word indicates to the processor that an interrupt of high enough priority is requesting service. Bits 0–4 indicate to the processor the type vector of the highest-priority source requesting service. Reading the Poll Word causes the In-Service bit of the highest priority source to be set.

It is desirable to be able to read the Poll Word information without guaranteeing service of any pending interrupt, i.e., not set the indicated in-service bit. The 80C188 provides a Poll Status Word in addition to the conventional Poll Word to allow this to be done. Poll Word information is duplicated in the Poll Status Word, but reading the Poll Status Word does not set the associated in-service bit. These words are located in two adjacent memory locations in the register file.

Master Mode Features

Programmable Priority

The user can program the interrupt sources into any of eight different priority levels. The programming is done by placing a 3-bit priority level (0–7) in the control register of each interrupt source. (A source with a priority level of 4 has higher priority over all priority levels from 5 to 7. Priority registers containing values lower than 4 have greater priority). All interrupt sources have preprogrammed default priority levels (see Table 4).

If two requests with the same programmed priority level are pending at once, the priority ordering scheme shown in Table 4 is used. If the serviced interrupt routine reenables interrupts, other interrupt requests can be serviced.

End-of-Interrupt Command

The end-of-interrupt (EOI) command is used by the programmer to reset the In-Service (IS) bit when an interrupt service routine is completed. The EOI command is issued by writing the proper pattern to the EOI register. There are two types of EOI commands, specific and nonspecific. The nonspecific command does not specify which IS bit is reset. When issued, the interrupt controller automatically resets the IS bit of the highest priority source with an active service routine. A specific EOI command requires that the programmer send the interrupt vector type to the interrupt controller indicating which source's IS bit is to be reset. This command is used when the fully nested structure has been disturbed or the highest priority IS bit that was set does not belong to the service routine in progress.

Trigger Mode

The four external interrupt pins can be programmed in either edge- or level-trigger mode. The control register for each external source has a level-trigger mode (LTM) bit. All interrupt inputs are active HIGH. In the edge sense mode or the level-trigger mode, the interrupt request must remain active (HIGH) until the interrupt request is acknowledged by the

80C188 CPU. In the edge-sense mode, if the level remains high after the interrupt is acknowledged, the input is disabled and no further requests will be generated. The input level must go LOW for at least one clock cycle to re-enable the input. In the level-trigger mode, no such provision is made: holding the interrupt input HIGH will cause continuous interrupt requests.

Interrupt Vectoring

The 80C186 Interrupt Controller will generate interrupt vectors for the integrated DMA channels and the integrated Timers. In addition, the Interrupt Controller will generate interrupt vectors for the external interrupt lines if they are not configured in Cascade or Special Fully Nested Mode. The interrupt vectors generated are fixed and cannot be changed (see Table 4).

Interrupt Controller Registers

The Interrupt Controller register model is shown in Figure 24. It contains 15 registers. All registers can both be read or written unless specified otherwise.

In-Service Register

This register can be read from or written into. The format is shown in Figure 25. It contains the In-Service bit for each of the interrupt sources. The In-Service bit is set to indicate that a source's service routine is in progress. When an In-Service bit is set, the interrupt controller will not generate interrupts to the CPU when it receives interrupt requests from devices with a lower programmed priority level. The TMR bit is the In-Service bit for all three timers; the D0 and D1 bits are the In-Service bits for the two DMA channels; the I0–I3 are the In-Service bits for the external interrupt pins. The IS bit is set when the processor acknowledges an interrupt request either by an interrupt acknowledge or by reading the poll register. The IS bit is reset at the end of the interrupt service routine by an end-of-interrupt command.

Interrupt Request Register

The internal interrupt sources have interrupt request bits inside the interrupt controller. The format of this register is shown in Figure 25. A read from this register yields the status of these bits. The TMR bit is the logical OR of all timer interrupt requests. D0 and D1 are the interrupt request bits for the DMA channels.

The state of the external interrupt input pins is also indicated. The state of the external interrupt pins is not a stored condition inside the interrupt controller, therefore the external interrupt bits cannot be written. The external interrupt request bits are set when an interrupt request is given to the interrupt controller, so if edge-triggered mode is selected, the bit in the register will be HIGH only after an inactive-to-active transition. For internal interrupt sources, the register bits are set when a request arrives and are reset when the processor acknowledges the requests.

Writes to the interrupt request register will affect the D0 and D1 interrupt request bits. Setting either bit will cause the corresponding interrupt request while clearing either bit will remove the corresponding interrupt request. All other bits in the register are read-only.

Mask Register

This is a 16-bit register that contains a mask bit for each interrupt source. The format for this register is shown in Figure 25. A one in a bit position corre-

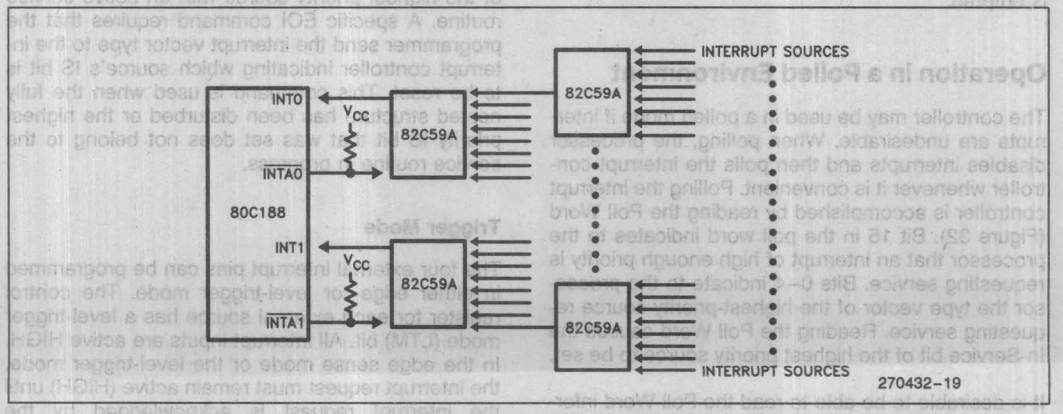


Figure 23. Cascade and Special Fully Nested Mode Interrupt Controller Connections

sponding to a particular source masks the source from generating interrupts. These mask bits are the exact same bits which are used in the individual control registers; programming a mask bit using the mask register will also change this bit in the individual control registers, and vice versa.

	OFFSET
INT3 CONTROL REGISTER	3EH
INT2 CONTROL REGISTER	3CH
INT1 CONTROL REGISTER	3AH
INT0 CONTROL REGISTER	38H
DMA 1 CONTROL REGISTER	36H
DMA 0 CONTROL REGISTER	34H
TIMER CONTROL REGISTER	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY MASK REGISTER	2AH
MASK REGISTER	28H
POLL STATUS REGISTER	26H
POLL REGISTER	24H
EOI REGISTER	22H

Figure 24. Interrupt Controller Registers (Master Mode)

Priority Mask Register

This register masks all interrupts below a particular interrupt priority level. The format of this register is shown in Figure 26. The code in the lower three bits of this register inhibits interrupts of priority lower (a higher priority number) than the code specified. For example, 100 written into this register masks interrupts of level five (101), six (110), and seven (111). The register is reset to seven (111) upon RESET so no interrupts are masked due to priority number.

Interrupt Status Register

This register contains general interrupt controller status information. The format of this register is shown in Figure 27. The bits in the status register have the following functions:

DHLT: DMA Halt Transfer; setting this bit halts all DMA transfers. It is automatically set whenever a non-maskable interrupt occurs, and it is reset when an IRET instruction is executed. This bit allows prompt service of all non-maskable interrupts. This bit may also be set by the programmer.

IRTx: These three bits represent the individual timer interrupt request bits. These bits differentiate between timer interrupts, since the timer IR bit in the interrupt request register is the "OR" function of all timer interrupt request. Note that setting any one of these three bits initiates an interrupt request to the interrupt controller.

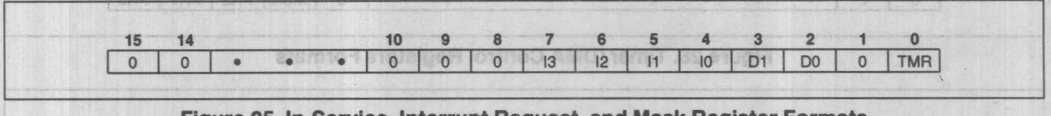


Figure 25. In-Service, Interrupt Request, and Mask Register Formats

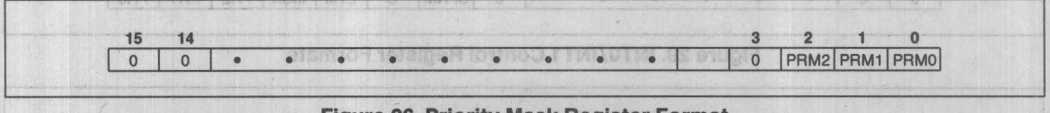


Figure 26. Priority Mask Register Format

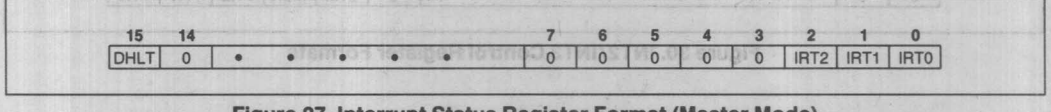


Figure 27. Interrupt Status Register Format (Master Mode)

Timer, DMA 0, 1; Control Register

These registers are the control words for all the internal interrupt sources. The format for these registers is shown in Figure 28. The three bit positions PR0, PR1, and PR2 represent the programmable priority level of the interrupt source. The MSK bit inhibits its interrupt requests from the interrupt source. The MSK bits in the individual control registers are the exact same bits as are in the Mask Register; modifying them in the individual control registers will also modify them in the Mask Register, and vice versa.

INT0-INT3 Control Registers

These registers are the control words for the four external input pins. Figure 29 shows the format of the INT0 and INT1 Control registers; Figure 30 shows the format of the INT2 and INT3 Control registers. In Cascade Mode or Special Fully Nested Mode, the control words for INT2 and INT3 are not used.

The bits in the various control registers are encoded as follows:

PRO-2: Priority programming information. Highest Priority = 000, Lowest Priority = 111

LTM: Level-trigger mode bit. 1 = level-triggered; 0 = edge-triggered. Interrupt Input levels are active high. In level-triggered mode, an interrupt is generated whenever the external line is high. In edge-triggered mode, an interrupt will be generated only when this level is preceded by an inactive-to-active transition on the line. In both cases, the level must remain active until the interrupt is acknowledged.

MSK: Mask bit, 1 = mask; 0 = non-mask.

C: Cascade mode bit, 1 = cascade; 0 = direct

SFNM: Special Fully Nested Mode bit, 1 = SFNM

EOI Register

The end of the interrupt register is a command register which can only be written into. The format of this register is shown in Figure 31. It initiates an EOI command when written to by the 80C188 CPU.

The bits in the EOI register are encoded as follows:

S_X: Encoded information that specifies an interrupt source vector type as shown in Table 4. For example, to reset the In-Service bit for DMA channel 0, these bits should be set to 01010, since the vector type for DMA channel 0 is 10.

NOTE:

To reset the single In-Service bit for any of the three timers, the vector type for timer 0 (8) should be written in this register.

NSPEC/SPEC: A bit that determines the type of EOI command. Nonspecific = 1, Specific = 0.

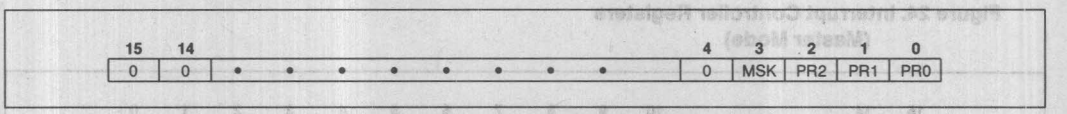


Figure 28. Timer/DMA Control Registers Formats

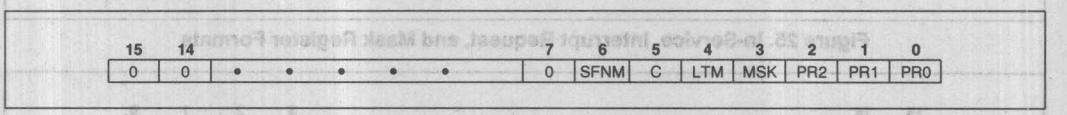


Figure 29. INT0/INT1 Control Register Formats

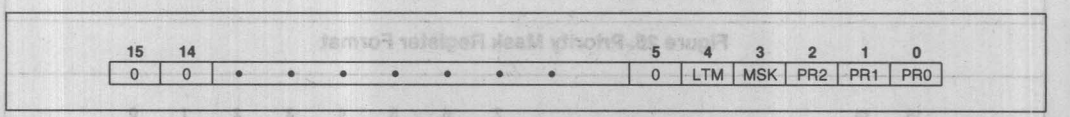


Figure 30. INT2/INT3 Control Register Formats

Poll and Poll Status Registers

These registers contain polling information. The format of these registers is shown in Figure 32. They can only be read. Reading the Poll register constitutes a software poll. This will set the IS bit of the highest priority pending interrupt. Reading the poll status register will not set the IS bit of the highest priority pending interrupt; only the status of pending interrupts will be provided.

Encoding of the Poll and Poll Status register bits are as follows:

S_X: Encoded information that indicates the vector type of the highest priority interrupting source. Valid only when INTREQ = 1.

INTREQ: This bit determines if an interrupt request is present. Interrupt Request = 1; no Interrupt Request = 0.

SLAVE MODE OPERATION

When Slave Mode is used, the internal 80C188 interrupt controller will be used as a slave controller to an external master interrupt controller. The internal 80C188 resources will be monitored by the internal interrupt controller, while the external controller functions as the system master interrupt controller.

Upon reset, the 80C188 will be in master mode. To provide for slave mode operation bit 14 of the relocation register should be set.

Because of pin limitations caused by the need to interface to an external 82C59A master, the internal interrupt controller will no longer accept external inputs. There are however, enough 80C188 interrupt controller inputs (internally) to dedicate one to each timer. In this mode, each timer interrupt source has its own mask bit, IS bit, and control word.

In Slave Mode each peripheral must be assigned a unique priority to ensure proper interrupt controller operation. Therefore, it is the programmer's responsibility to assign correct priorities and initialize interrupt control registers before enabling interrupts.

Slave Mode External Interface

The configuration of the 80C188 with respect to an external 82C59A master is shown in Figure 33. The INT0 (Pin 45) input is used as the 80C188 CPU interrupt input. IRQ (Pin 41) functions as an output to send the 80C188 slave-interrupt-request to one of the 8 master-PIC-inputs.

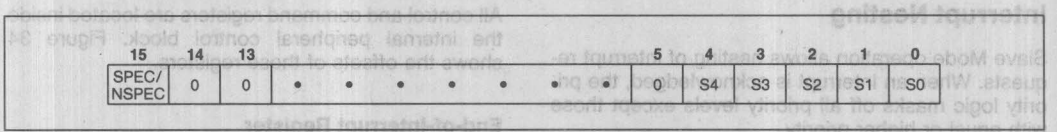


Figure 31. EOI Register Format

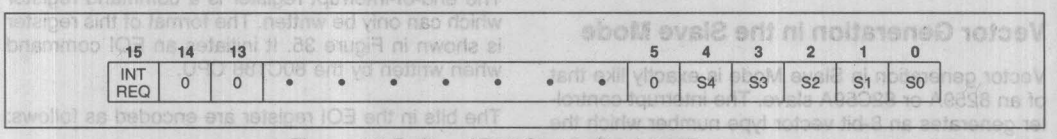


Figure 32. Poll and Poll Status Register Format

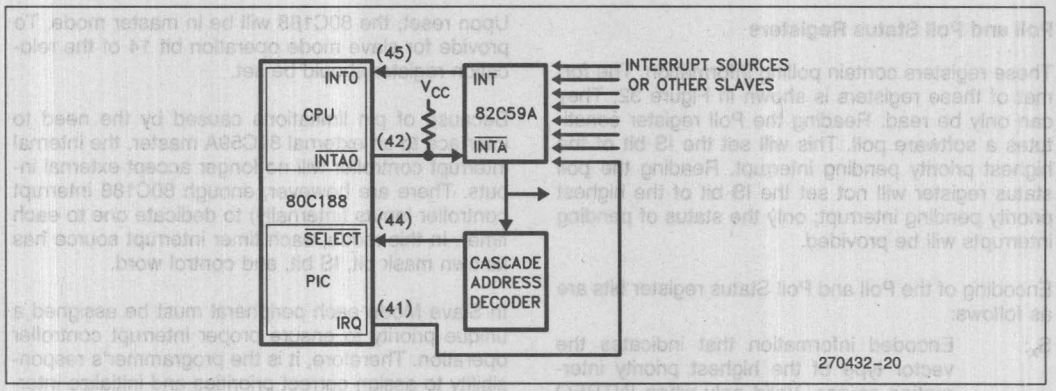


Figure 33. Slave Mode Interrupt Controller Connections

Correct master-slave interface requires decoding of the slave addresses (CAS0-2). Slave 82C59As do this internally. Because of pin limitations, the 80C188 slave address will have to be decoded externally. $\overline{\text{SELECT}}$ (Pin 44) is used as a slave-select input. Note that the slave vector address is transferred internally, but the READY input must be supplied externally.

$\overline{\text{INTA0}}$ (Pin 42) is used as an acknowledge output, suitable to drive the $\overline{\text{INTA}}$ input of an 82C59A.

Interrupt Nesting

Slave Mode operation allows nesting of interrupt requests. When an interrupt is acknowledged, the priority logic masks off all priority levels except those with equal or higher priority.

Vector Generation in the Slave Mode

Vector generation in Slave Mode is exactly like that of an 8259A or 82C59A slave. The interrupt controller generates an 8-bit vector type number which the CPU multiplies by four to use as an address into the vector table. The five most significant bits of this type number are user-programmable while the three least significant bits are defined according to Figure 34. The significant five bits of the vector are programmed by writing to the Interrupt Vector register at offset 20H.

Specific End-of-Interrupt

In Slave Mode the specific EOI command operates to reset an in-service bit of a specific priority. The user supplies a 3-bit priority-level value that points to an in-service bit to be reset. The command is executed by writing the correct value in the Specific EOI register at offset 22H.

Interrupt Controller Registers in the Slave Mode

All control and command registers are located inside the internal peripheral control block. Figure 34 shows the offsets of these registers.

End-of-Interrupt Register

The end-of-interrupt register is a command register which can only be written. The format of this register is shown in Figure 35. It initiates an EOI command when written by the 80C188 CPU.

The bits in the EOI register are encoded as follows:

VT_X: Three least-significant vector type bits corresponding to the source for which the IS bit is to be reset. Figure 34 indicates these bits.

In-Service Register

This register can be read from or written into. It contains the in-service bit for each of the internal interrupt sources. The format for this register is shown in Figure 36. Bit positions 2 and 3 correspond to the DMA channels; positions 0, 4, and 5 correspond to the integral timers. The source's IS bit is set when the processor acknowledges its interrupt request.

Interrupt Request Register

This register indicates which internal peripherals have interrupt requests pending. The format of this register is shown in Figure 36. The interrupt request bits are set when a request arrives from an internal source, and are reset when the processor acknowledges the request. As in Master Mode, D0 and D1 are read/write; all other bits are read only.

Mask Register

This register contains a mask bit for each interrupt source. The format for this register is shown in Figure 36. If the bit in this register corresponding to a particular interrupt source is set, any interrupts from that source will be masked. These mask bits are exactly the same bits which are used in the individual control registers, i.e., changing the state of a mask bit in this register will also change the state of the mask bit in the individual interrupt control register corresponding to the bit.

Control Registers

These registers are the control words for all the internal interrupt sources. The format of these registers is shown in Figure 37. Each of the timers and both of the DMA channels have their own Control Register.

The bits of the Control Registers are encoded as follows:

pr_x: 3-bit encoded field indicating a priority level for the source.

msk: mask bit for the priority level indicated by pr_x bits.

	OFFSET
TIMER 2 CONTROL REGISTER (VECTOR TYPE xxxxx101)	3AH
TIMER 1 CONTROL REGISTER (VECTOR TYPE xxxxx100)	38H
DMA 1 CONTROL REGISTER (VECTOR TYPE xxxxx011)	36H
DMA 0 CONTROL REGISTER (VECTOR TYPE xxxxx010)	34H
TIMER 0 CONTROL REGISTER (VECTOR TYPE xxxxx000)	32H
INTERRUPT STATUS REGISTER	30H
INTERRUPT-REQUEST REGISTER	2EH
IN-SERVICE REGISTER	2CH
PRIORITY-LEVEL MASK REGISTER	2AH
MASK REGISTER	28H
SPECIFIC EOI REGISTER	22H
INTERRUPT VECTOR REGISTER	20H

Figure 34. Interrupt Controller Registers (Slave Mode)

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	0	0	0	VT2	VT1	VT0

Figure 35. Specific EOI Register Format

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	TMR2	TMR1	D1	D0	0	TMR0

Figure 36. In-Service, Interrupt Request, and Mask Register Format

Interrupt Vector Register

This register provides the upper five bits of the interrupt vector address. The format of this register is shown in Figure 38. The interrupt controller itself provides the lower three bits of the interrupt vector as determined by the priority level of the interrupt request.

The format of the bits in this register is:

t_x: 5-bit field indicating the upper five bits of the vector address.

Priority-Level Mask Register

This register indicates the lowest priority-level interrupt which will be serviced.

The encoding of the bits in this register is:

m_x: 3-bit encoded field indication priority-level value. All levels of lower priority will be masked.

Interrupt Status Register

This register is defined as in Master Mode except that DHLT is not implemented (see Figure 27).

Interrupt Controller and Reset

Upon RESET, the interrupt controller will perform the following actions:

- All SFNM bits reset to 0, implying Fully Nested Mode.
- All PR bits in the various control registers set to 1. This places all sources at lowest priority (level 111).
- All LTM bits reset to 0, resulting in edge-sense mode.
- All Interrupt Service bits reset to 0.
- All Interrupt Request bits reset to 0.
- All MSK (Interrupt Mask) bits set to 1 (mask).
- All C (Cascade) bits reset to 0 (non-Cascade).
- All PRM (Priority Mask) bits set to 1, implying no levels masked.
- Initialized to Master Mode.

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	0	0	MSK	PR2	PR1	PR0

Figure 37. Control Word Format

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	t4	t3	t2	t1	t0	0	0	0

Figure 38. Interrupt Vector Register Format

15	14	13	•	•	•	•	8	7	6	5	4	3	2	1	0
0	0	0					0	0	0	0	0	0	m2	m1	m0

Figure 39. Priority Level Mask Register

Enhanced Mode Operation

In Compatible Mode the 80C188 operates with all the features of the NMOS 80188, with the exception of 8087 support (i.e. no numeric coprocessing is possible). Queue-Status information is still available for design purposes other than 8087 support.

All the Enhanced Mode features are completely masked when in Compatible Mode. A write to any of the Enhanced Mode registers will have no effect, while a read will not return any valid data.

In Enhanced Mode, the 80C188 will operate with Power-Save and DRAM refresh, in addition to all the Compatible Mode features.

Entering Enhanced Mode

Enhanced mode can be entered by tying the RESET output signal from the 80C188 to the TEST/BUSY input.

Queue-Status Mode

The queue-status mode is entered by strapping the $\overline{RD}$ pin low. $\overline{RD}$ is sampled at RESET and if LOW, the 80C188 will reconfigure the ALE and $\overline{WR}$ pins to be QS0 and QS1 respectively. This mode is available on the 80C188 in both Compatible and Enhanced Modes.

DRAM Refresh Control Unit Description

The Refresh Control Unit (RCU) automatically generates DRAM refresh bus cycles. The RCU operates only in Enhanced Mode. After a programmable period of time, the RCU generates a memory read request to the BIU. If the address generated during a refresh bus cycle is within the range of a properly programmed chip select, that chip select will be activated when the BIU executes the refresh bus cycle. The ready logic and wait states programmed for that region will also be in force. If no chip select is activated, then external ready is automatically required to terminate the refresh bus cycle.

If the HLDA pin is active when a DRAM refresh request is generated (indicating a bus hold condition), then the 80C188 will deactivate the HLDA pin in order to perform a refresh cycle. The circuit external to the 80C188 must remove the HOLD signal for at least one clock in order to execute the refresh cycle. The sequence of HLDA going inactive while HOLD is being held active can be used to signal a pending refresh request.

All registers controlling DRAM refresh may be read and written in Enhanced Mode. When the processor is operating in Compatible Mode, they are deselected and are therefore inaccessible. Some fields of these registers cannot be written and are always read as zeros.

DRAM Refresh Addresses

The address generated during a refresh cycle is determined by the contents of the MDRAM register (see Figure 40) and the contents of a 9-bit counter. Figure 41 illustrates the origin of each bit.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
MDRAM: Offset E0H	M6	M5	M4	M3	M2	M1	M0	0	0	0	0	0	0	0	0	0

Bits 0–8: Reserved, read back as 0.

Bits 9–15: M0–M6, are address bits A13–A19 of the 20-bit memory refresh address. These bits should correspond to any chip select address to be activated for the DRAM partition. These bits are cleared to 0 on RESET.

Figure 40. Memory Partition Register

A19	A18	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0
M6	M5	M4	M3	M2	M1	M0	0	0	0	CA8	CA7	CA6	CA5	CA4	CA3	CA2	CA1	CA0	1

M6–M0: Bits defined by MDRAM Register

CA8–CA0: Bits defined by refresh address counter. These bits change according to a linear/feedback shift register; they do not directly follow a binary count.

Figure 41. Addresses Generated by RCU

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
CDRAM: Offset E2H	0	0	0	0	0	0	0	C8	C7	C6	C5	C4	C3	C2	C1	C0

Bits 0–8: C0–C8, clock divisor register, holds the number of CLKOUT cycles between each refresh request.

Bits 9–15: Reserved, read back as 0.

Figure 42. Clock Pre-Scaler Register

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
EDRAM: Offset E4H	E	0	0	0	0	0	0	T8	T7	T6	T5	T4	T3	T2	T1	T0

Bits 0–8: T0–T8, refresh clock counter outputs. Read only.

Bits 9–14: Reserved, read back as 0.

Bit 15: Enable RCU, set to 0 on RESET.

Figure 43. Enable RCU Register

Refresh Control Unit Programming and Operation

After programming the MDRAM and the CDRAM registers (Figures 40 and 42), the RCU is enabled by setting the "E" bit in the EDRAM register (Figure 43). The clock counter (T0–T8 of EDRAM) will be loaded from C0–C8 of CDRAM during T_3 of instruction cycle that sets the "E" bit. The clock counter is then decremented at each subsequent CLKOUT.

A refresh is requested when the value of the counter has reached 1 and the counter is reloaded from CDRAM. In order to avoid missing refresh requests, the value in the CDRAM register should always be at least 18 (12H). Clearing the "E" bit at anytime will clear the counter and stop refresh requests, but will not reset the refresh address counter.

POWER-SAVE CONTROL

Power Save Operation

The 80C188, when in Enhanced Mode, can enter a power saving state by internally dividing the processor clock frequency by a programmable factor. This divided frequency is also available at the CLKOUT pin. The PDCON register contains the two-bit fields for selecting the clock division factor and the enable bit.

All internal logic, including the Refresh Control Unit and the timers, will have their clocks slowed down by the division factor. To maintain a real time count or a fixed DRAM refresh rate, these peripherals must be re-programmed when entering and leaving the power-save mode.

The power-save mode is exited whenever an interrupt is processed by automatically resetting the enable bit. If the power-save mode is to be re-entered after serving the interrupt, the enable bit will need to be set in software before returning from the interrupt routine.

The internal clocks of the 80C188 will begin to be divided during the T_3 state of the instruction cycle that sets the enable bit. Clearing the enable bit will restore full speed in the T_3 state of that instruction.

At no time should the internal clock frequency be allowed to fall below 0.5 MHz. This is the minimum operational frequency of the 80C188. For example, an 80C188 running with a 12 MHz crystal (6 MHz CLOCKOUT) should never have a clock divisor greater than eight.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PDCON: Offset F0H	E	0	0	0	0	0	0	0	0	0	0	0	0	0	F1	F0

Bits 0–1: Clock Divisor Select

F1	F0	Division Factor
0	0	divide by 1
0	1	divide by 4
1	0	divide by 8
1	1	divide by 16

Bits 2–14: Reserved, read back as zero.

Bit 15: Enable Power Save Mode. Set to zero on RESET.

Figure 44. Power-Save Control Register

ONCE™ Test Mode

To facilitate testing and inspection of devices when fixed into a target system, the 80C188 has a test mode available which allows all pins to be placed in a high-impedance state. ONCE stands for "ON Circuit Emulation". When placed in this mode, the 80C188 will put all pins in the high-impedance state until RESET.

The ONCE mode is selected by tying the $\overline{UCS}$ and the $\overline{LCS}$ LOW during RESET. These pins are sampled on the low-to-high transition of the $\overline{RES}$ pin. The $\overline{UCS}$ and the $\overline{LCS}$ pins have weak internal pull-up resistors similar to the $\overline{RD}$ and $\overline{TEST}$ pins to guarantee normal operation.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
E	0	0	0	0	0	0	0	0	0	0	0	0	0	F1	F0

PDCON (Write Only)

Bits 0–1: Clock Divisor Select

F1	F0	Division Factor
0	0	divide by 1
0	1	divide by 4
1	0	divide by 8
1	1	divide by 16

Bits 2–14: Reserved, read back as zero.

Bit 15: Enable Power Save Mode. Set to zero on RESET.

Figure 44. Power-Save Control Register

ONCE™ Test Mode

To facilitate testing and inspection of devices when soldered into a target system, the 80C188 has a test mode available which allows all pins to be placed in a high-impedance state. ONCE stands for "ON Circuit Emulation". When placed in this mode, the 80C188 will put all pins in the high-impedance state until RESET.

The ONCE mode is selected by tying the UCS and the LCS LOW during RESET. These pins are sampled on the low-to-high transition of the RES pin. The UCS and the LCS pins have weak internal pull-up resistors similar to the RD and TEST pins to guarantee normal operation.

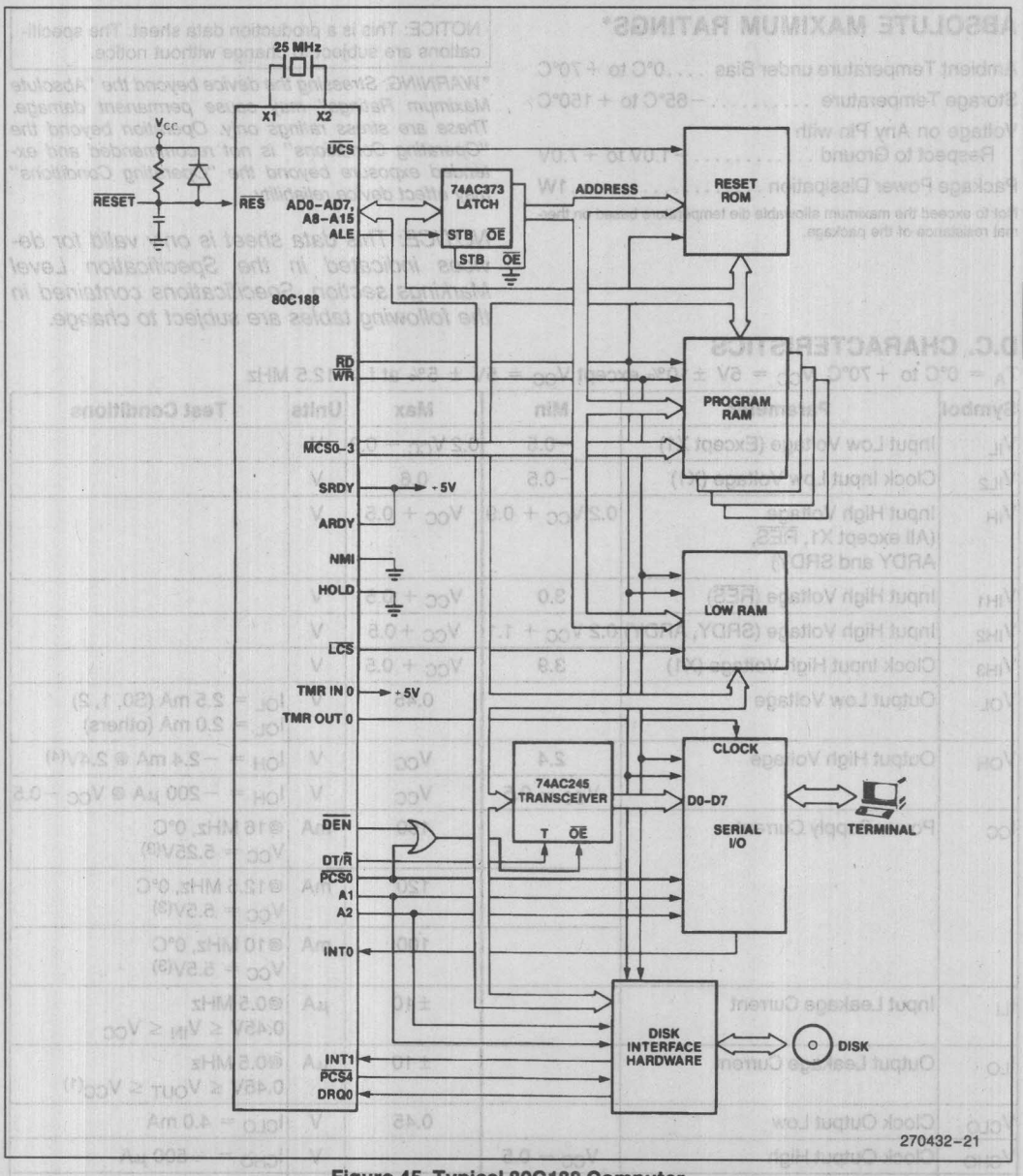


Figure 45. Typical 80C188 Computer

ABSOLUTE MAXIMUM RATINGS*

Ambient Temperature under Bias ....0°C to +70°C
Storage Temperature .....−65°C to +150°C
Voltage on Any Pin with Respect to Ground .....−1.0V to +7.0V
Package Power Dissipation 1W

Not to exceed the maximum allowable die temperature based on thermal resistance of the package.

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

NOTICE: This data sheet is only valid for devices indicated in the Specification Level Markings section. Specifications contained in the following tables are subject to change.

D.C. CHARACTERISTICS

T_A = 0°C to +70°C, V_{CC} = 5V ±10% except V_{CC} = 5V ± 5% at f > 12.5 MHz

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage (Except X1)	−0.5	0.2 V_{CC} − 0.3	V	
V_{IL2}	Clock Input Low Voltage (X1)	−0.5	0.6	V	
V_{IH}	Input High Voltage (All except X1, $\overline{RES}$, ARDY and SRDY)	0.2 V_{CC} + 0.9	V_{CC} + 0.5	V	
V_{IH1}	Input High Voltage ($\overline{RES}$)	3.0	V_{CC} + 0.5	V	
V_{IH2}	Input High Voltage (SRDY, ARDY)	0.2 V_{CC} + 1.1	V_{CC} +0.5	V	
V_{IH3}	Clock Input High Voltage (X1)	3.9	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 2.5 mA (S0, 1, 2) I_{OL} = 2.0 mA (others)
V_{OH}	Output High Voltage	2.4	V_{CC}	V	I_{OH} = −2.4 mA @ 2.4V(4)
		V_{CC} − 0.5	V_{CC}	V	I_{OH} = −200 μA @ V_{CC} −0.5
I_{CC}	Power Supply Current		150	mA	@16 MHz, 0°C V_{CC} = 5.25V(3)
			120	mA	@12.5 MHz, 0°C V_{CC} = 5.5V(3)
			100	mA	@10 MHz, 0°C V_{CC} = 5.5V(3)
I_{LI}	Input Leakage Current		±10	μA	@0.5 MHz 0.45V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±10	μA	@0.5 MHz 0.45V ≤ V_{OUT} ≤ V_{CC}(1)
V_{CLO}	Clock Output Low		0.45	V	I_{CLO} = 4.0 mA
V_{CHO}	Clock Output High	V_{CC} − 0.5		V	I_{CHO} = −500 μA
C_{IN}	Input Capacitance		10	pF	@ 1 MHz(2)
C_{IO}	Output or I/O Capacitance		20	pF	@ 1 MHz(2)

NOTES:
1. Pins being floated during HOLD or by invoking the ONCE Mode.
2. Characterization conditions are a) Frequency = 1 MHz; b) Unmeasured pins at GND; c) V_{IN} at +5.0V or 0.45V. This parameter is not tested.
3. Current is measured with the device in RESET with X1 and X2 driven and all other non-power pins open.
4. $\overline{RD}$/QSMD, $\overline{UCS}$, $\overline{LCS}$, $\overline{TEST}$ pins have internal pullup devices. Loading some of these pins above I_{OH} = −200 μA can cause the 80C188 to go into alternative modes of operation. See the section on Local Bus Controller and Reset for details.

POWER SUPPLY CURRENT

Current is linearly proportional to clock frequency and is measured with the device in RESET with X1 and X2 driven and all other non-power pins open.

Maximum current is given by I_{CC} = 8.4 mA × freq. (MHz) + 15 mA.

Typical current is given by I_{CC} (typ.) = 6.4 mA X freq. (MHz) + 4.0 mA. "Typicals" are based on a limited number of samples taken from early manufacturing lots measured at V_{CC} = 5V and room temperature. "Typicals" are not guaranteed.

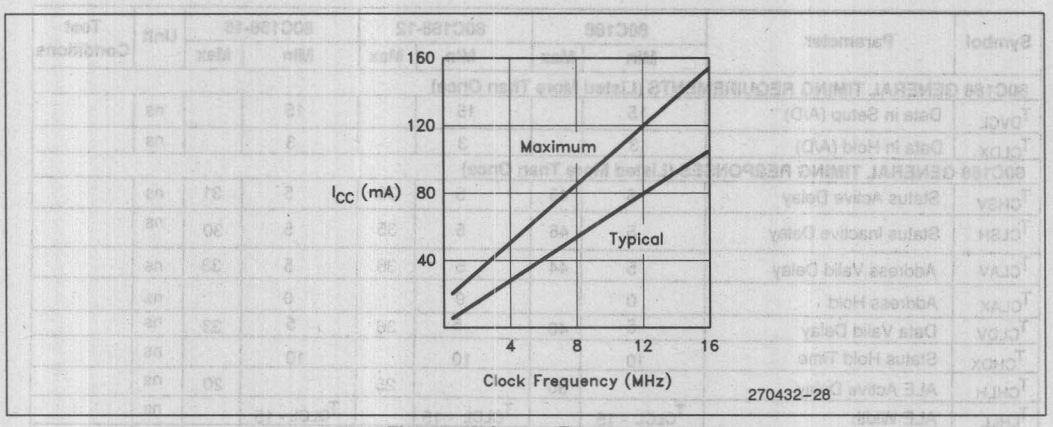


Figure 46. I_{CC} vs Frequency

A. C. CHARACTERISTICS

MAJOR CYCLE TIMINGS (READ CYCLE)

$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.

All output test conditions are with $C_L = 50\text{-}200$ pF (10 MHz) and $C_L = 50\text{-}100$ pF (12.5-16 MHz).

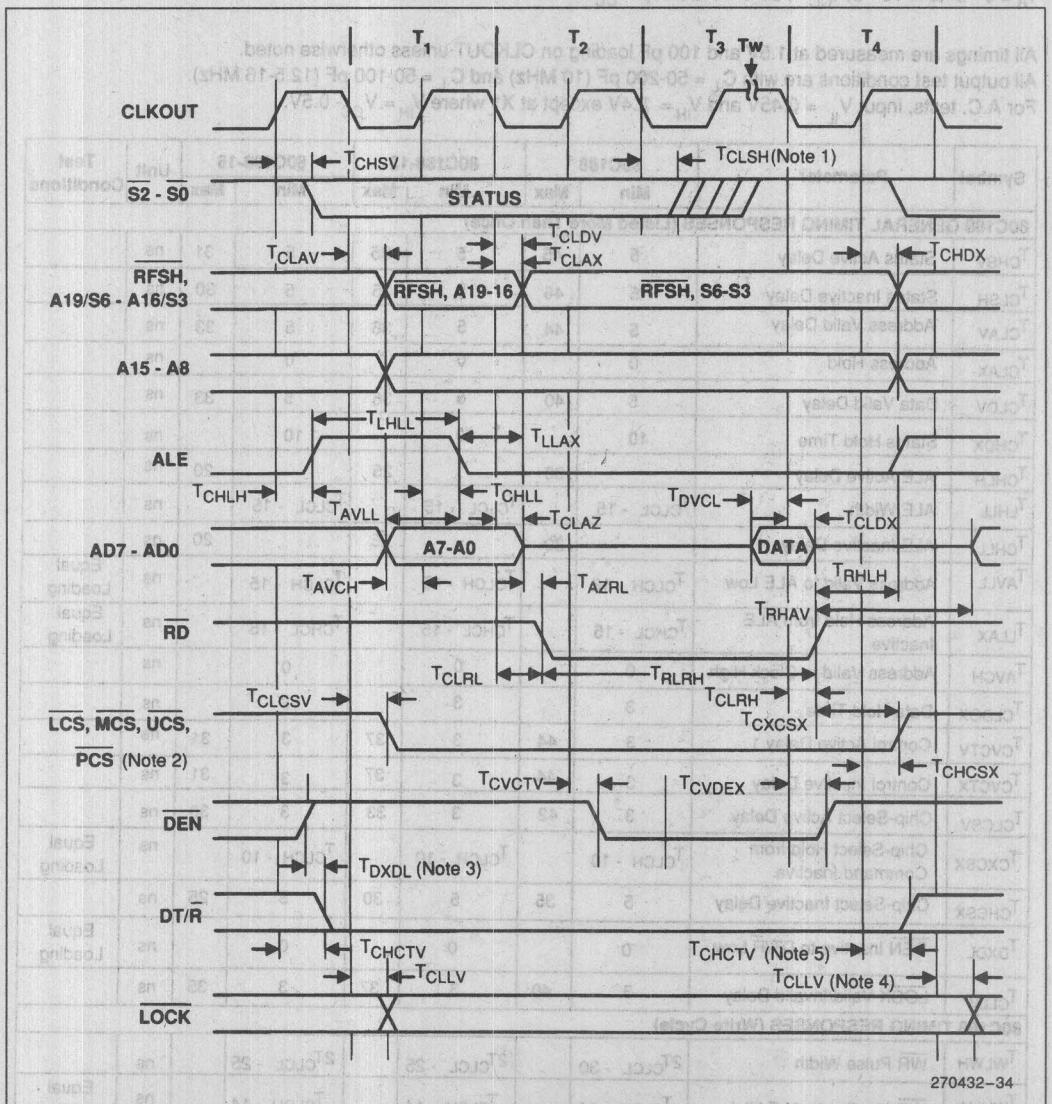
For A.C. tests, input $V_{IL} = 0.45V$ and $V_{IH} = 2.4V$ except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 GENERAL TIMING REQUIREMENTS (Listed More Than Once)									
T_{DVCL}	Data in Setup (A/D)	15		15		15		ns	
T_{CLDX}	Data in Hold (A/D)	3		3		3		ns	
80C188 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	$T_{CLCL} - 15$		$T_{CLCL} - 15$		$T_{CLCL} - 15$		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	$T_{CLCH} - 18$		$T_{CLCH} - 15$		$T_{CLCH} - 15$		ns	Equal Loading
T_{LLAX}	Address Hold from ALE Inactive	$T_{CHCL} - 15$		$T_{CHCL} - 15$		$T_{CHCL} - 15$		ns	Equal Loading
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CLCSV}	Chip-Select Active Delay	3	42	3	33	3	30	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	$T_{CLCH} - 10$		$T_{CLCH} - 10$		$T_{CLCH} - 10$		ns	Equal Loading
T_{CHCSX}	Chip-Select Inactive Delay	5	35	5	30	5	25	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVDEX}	$\overline{DEN}$ Inctive Delay	5	44	5	37	5	31	ns	
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	
80C188 TIMING RESPONSES (Read Cycle)									
T_{AZRL}	Address Float to $\overline{RD}$ Active	0		0		0		ns	
T_{CLRL}	$\overline{RD}$ Active Delay	5	44	5	37	5	31	ns	
T_{RLRH}	$\overline{RD}$ Pulse Width	$2T_{CLCL} - 30$		$2T_{CLCL} - 25$		$2T_{CLCL} - 25$		ns	
T_{CLRH}	$\overline{RD}$ Inactive Delay	5	44	5	37	5	31	ns	
T_{RHLH}	$\overline{RD}$ Inactive to ALE High	$T_{CLCH} - 14$		$T_{CLCH} - 14$		$T_{CLCH} - 14$		ns	Equal Loading
T_{RHAV}	$\overline{RD}$ Inactive to Address Active	$T_{CLCL} - 15$		$T_{CLCL} - 15$		$T_{CLCL} - 15$		ns	Equal Loading

270432-33

A.C. CHARACTERISTICS

READ CYCLE WAVEFORMS



NOTES:
1. Status inactive in state preceding T_4.
2. If latched A_1 and A_2 are selected instead of $\overline{PCS5}$ and $\overline{PCS6}$, only T_{CLCSV} is applicable.
3. For write cycle followed by read cycle.
4. T_1 of next bus cycle.
5. Changes in T-state preceding next bus cycle if followed by write.

A. C. CHARACTERISTICS

MAJOR CYCLE TIMINGS (WRITE CYCLE)

$T_A = 0\ ^{\circ}C$ to $+70\ ^{\circ}C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

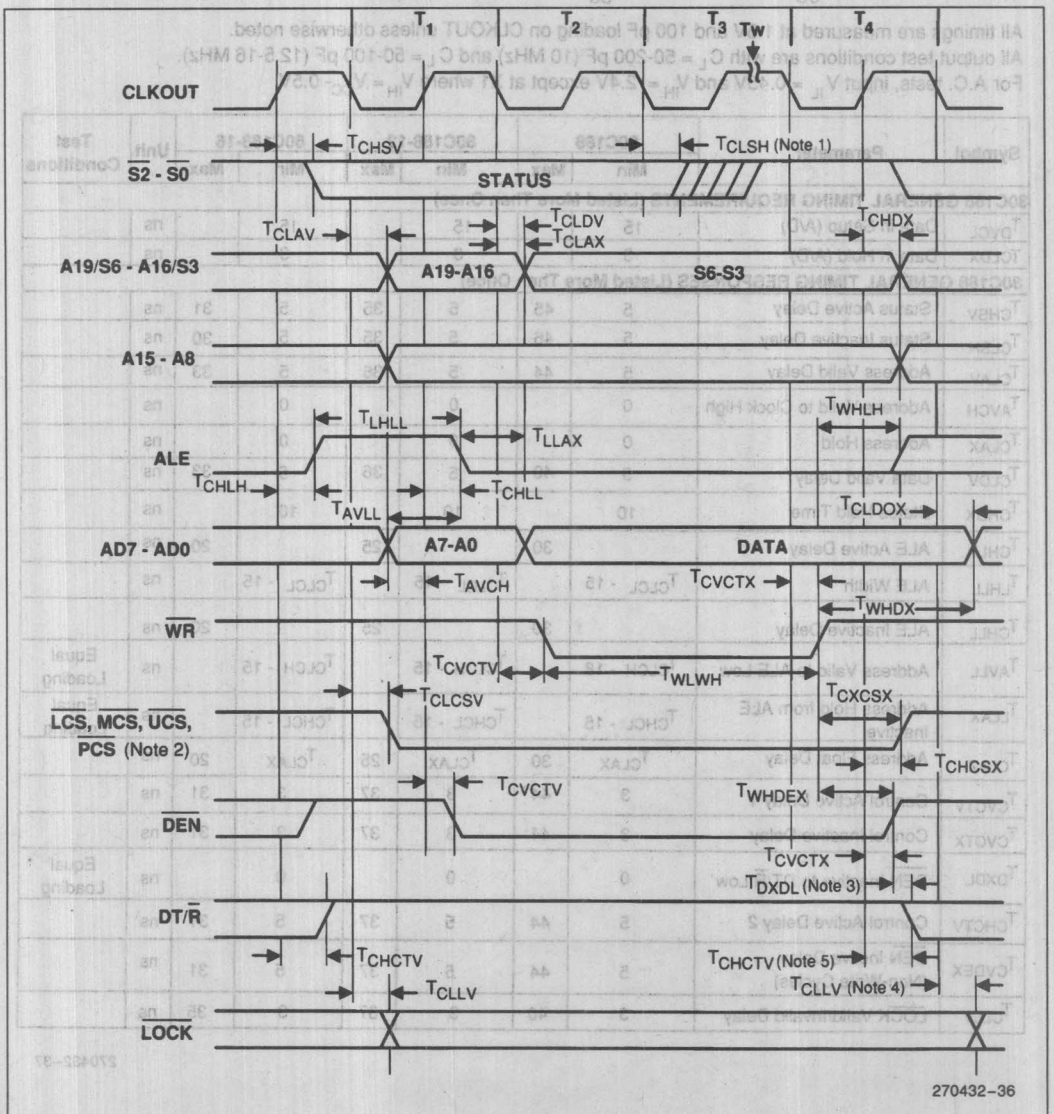
All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	T_{CLCH} - 18		T_{CLCH} - 15		T_{CLCH} - 15		ns	Equal Loading
T_{LLAX}	Address Hold from ALE Inactive	T_{CHCL} - 15		T_{CHCL} - 15		T_{CHCL} - 15		ns	Equal Loading
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLDOX}	Data Hold Time	3		3		3		ns	
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVCTX}	Control Inactive Delay	3	44	3	37	3	31	ns	
T_{CLCSV}	Chip-Select Active Delay	3	42	3	33	3	30	ns	
T_{CXCSX}	Chip-Select Hold from Command Inactive	T_{CLCH} - 10		T_{CLCH} - 10		T_{CLCH} - 10		ns	Equal Loading
T_{CHCSX}	Chip-Select Inactive Delay	5	35	5	30	5	25	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	
80C188 TIMING RESPONSES (Write Cycle)									
T_{WLWH}	$\overline{WR}$ Pulse Width	$2T_{CLCL}$ - 30		$2T_{CLCL}$ - 25		$2T_{CLCL}$ - 25		ns	
T_{WHLH}	$\overline{WR}$ Inactive to ALE High	T_{CLCH} - 14		T_{CLCH} - 14		T_{CLCH} - 14		ns	Equal Loading
T_{WHDX}	Data Hold After $\overline{WR}$	T_{CLCL} - 34		T_{CLCL} - 20		T_{CLCL} - 20		ns	Equal Loading
T_{WHDEX}	$\overline{WR}$ Inactive to $\overline{DEN}$ Inactive	T_{CLCH} - 10		T_{CLCH} - 10		T_{CLCH} - 10		ns	Equal Loading

270432-35

A.C. CHARACTERISTICS

WRITE CYCLE WAVEFORMS



NOTES:
1. Status inactive in state preceding T_4.
2. If latched A_1 and A_2 are selected instead of $\overline{PCS5}$ and $\overline{PCS6}$, only T_{CLCSV} is applicable.
3. For write cycle followed by read cycle.
4. T_1 of next bus cycle.
5. Changes in T-state preceding next bus cycle if followed by read, INTA, or halt.

A. C. CHARACTERISTICS

MAJOR CYCLE TIMINGS (INTERRUPT ACKNOWLEDGE CYCLE)

$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

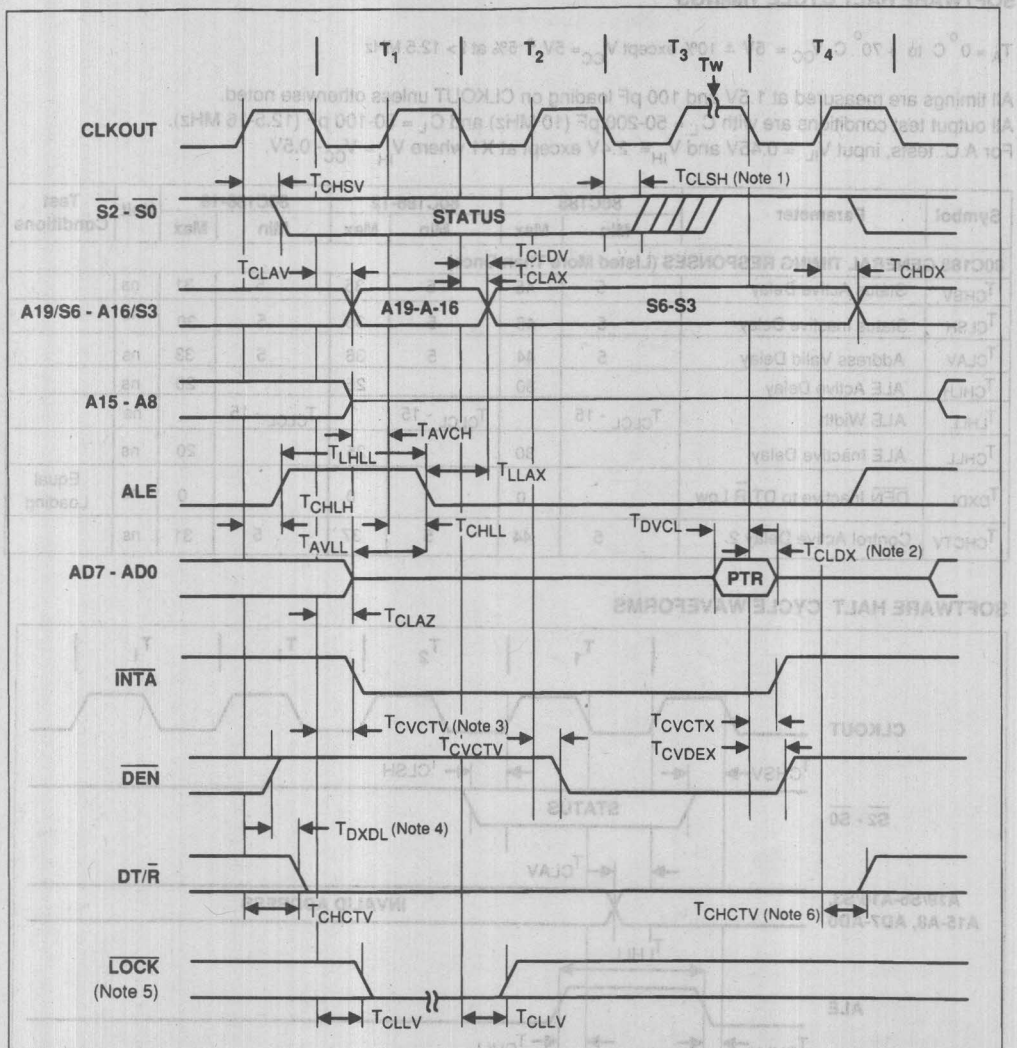
All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with $C_L = 50\text{-}200$ pF (10 MHz) and $C_L = 50\text{-}100$ pF (12.5-16 MHz).
For A.C. tests, input $V_{IL} = 0.45V$ and $V_{IH} = 2.4V$ except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 GENERAL TIMING REQUIREMENTS (Listed More Than Once)									
T_{DVCL}	Data in Setup (A/D)	15		15		15		ns	
TCLDX	Data in Hold (A/D)	3		3		3		ns	
80C188 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{AVCH}	Address Valid to Clock High	0		0		0		ns	
T_{CLAX}	Address Hold	0		0		0		ns	
T_{CLDV}	Data Valid Delay	5	40	5	36	5	33	ns	
T_{CHDX}	Status Hold Time	10		10		10		ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	$T_{CLCL} - 15$		$T_{CLCL} - 15$		$T_{CLCL} - 15$		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{AVLL}	Address Valid to ALE Low	$T_{CLCH} - 18$		$T_{CLCH} - 15$		$T_{CLCH} - 15$		ns	Equal Loading
T_{LLAX}	Address Hold from ALE Inactive	$T_{CHCL} - 15$		$T_{CHCL} - 15$		$T_{CHCL} - 15$		ns	Equal Loading
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CVCTV}	Control Active Delay 1	3	44	3	37	3	31	ns	
T_{CVCTX}	Control Inactive Delay	3	44	3	37	3	31	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low	0		0		0		ns	Equal Loading
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	
T_{CVDEX}	$\overline{DEN}$ Inctive Delay (Non-Write Cycles)	5	44	5	37	5	31	ns	
T_{CLLV}	$\overline{LOCK}$ Valid/Invalid Delay	3	40	3	37	3	35	ns	

270432-37

A. C. CHARACTERISTICS

INTERRUPT ACKNOWLEDGE CYCLE WAVEFORMS



NOTES:

1. Status inactive in state preceding T_4.
2. The data hold time lasts only until $\overline{INTA}$ goes inactive, even if the $\overline{INTA}$ transition occurs prior to T_{CLDX}(min).
3. $\overline{INTA}$ occurs one clock later in Slave Mode.
4. For write cycle followed by interrupt acknowledge cycle.
5. $\overline{LOCK}$ is active upon T_1 of the first interrupt acknowledge cycle and inactive upon T_2 of the second interrupt acknowledge cycle.
6. Changes in T-state preceding next bus cycle if followed by write.

270432-38

A. C. CHARACTERISTICS

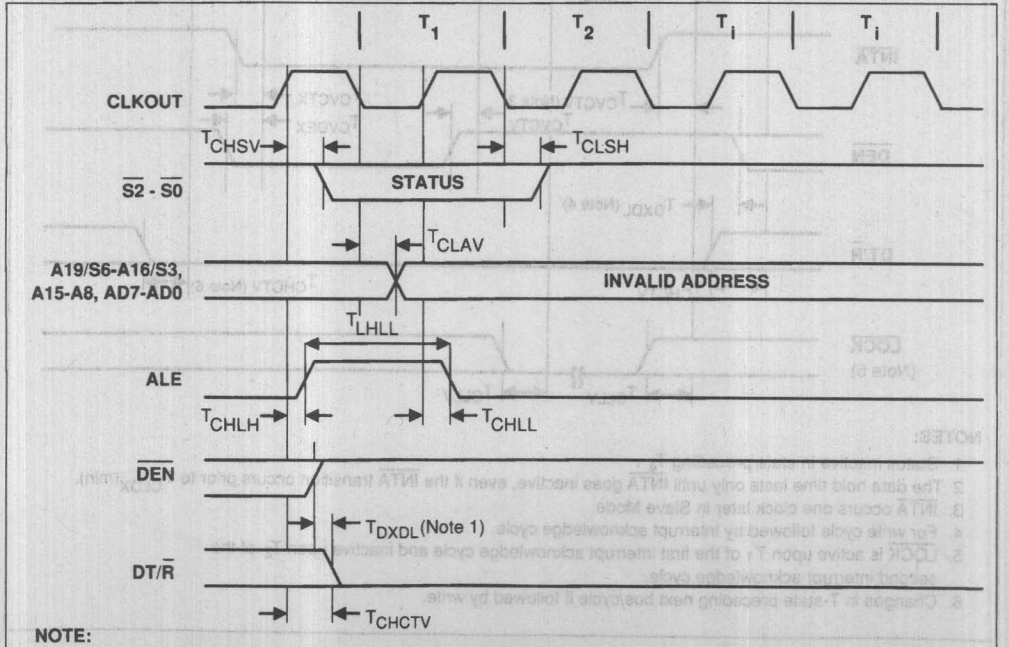
SOFTWARE HALT CYCLE TIMINGS

$T_A = 0^\circ C$ to $+70^\circ C$, V_{CC} = 5V ± 10% except V_{CC} = 5V ± 5% at f > 12.5 MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CHSV}	Status Active Delay	5	45	5	35	5	31	ns	
T_{CLSH}	Status Inactive Delay	5	46	5	35	5	30	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
T_{CHLH}	ALE Active Delay		30		25		20	ns	
T_{LHLL}	ALE Width	T_{CLCL} - 15		T_{CLCL} - 15		T_{CLCL} - 15		ns	
T_{CHLL}	ALE Inactive Delay		30		25		20	ns	
T_{DXDL}	$\overline{DEN}$ Inactive to DT/$\overline{R}$ Low		0		0		0	ns	Equal Loading
T_{CHCTV}	Control Active Delay 2	5	44	5	37	5	31	ns	

SOFTWARE HALT CYCLE WAVEFORMS



NOTE:
1. For write cycle followed by halt cycle.

270432-39

A. C. CHARACTERISTICS

CLOCK TIMINGS

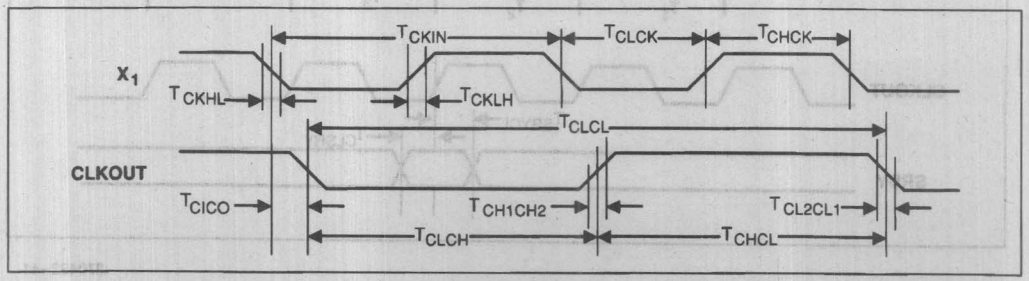
$T_A = 0^\circ C$ to $+70^\circ C$, V_{CC}= 5V ±10% except V_{CC}= 5V ±5% at f > 12.5 MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 CLKIN REQUIREMENTS Measurements taken with following conditions: External clock input to X1 and X2 not connected (float)									
T_{CKIN}	CLKIN Period	50	1000	40	1000	31.25	1000	ns	
T_{CLCK}	CLKIN Low Time	20		16		13		ns	1.5 V(2)
T_{CHCK}	CLKIN High Time	20		16		13		ns	1.5 V(2)
T_{CKHL}	CLKIN Fall Time		5		5		5	ns	3.5 to 1.0V
T_{CKLH}	CLKIN Rise Time		5		5		5	ns	1.0 to 3.5V
80C188 CLKOUT TIMING									
T_{CICO}	CLKIN to CLKOUT Skew		25		21		17	ns	
T_{CLCL}	CLKOUT Period	100	2000	80	2000	62.5	2000	ns	
T_{CLCH}	CLKOUT Low Time	0.5 T_{CLCL} -8		0.5 T_{CLCL} -7		0.5 T_{CLCL} -7		ns	C_L=100pF(2)
		0.5 T_{CLCL} -6		0.5 T_{CLCL} -5		0.5 T_{CLCL} -5		ns	C_L=50pF(3)
T_{CHCL}	CLKOUT High Time	0.5 T_{CLCL} -8		0.5 T_{CLCL} -7		0.5 T_{CLCL} -7		ns	C_L=100pF(4)
		0.5 T_{CLCL} -6		0.5 T_{CLCL} -5		0.5 T_{CLCL} -5		ns	C_L=50pF(3)
T_{CH1CH2}	CLKOUT Rise Time		10		10		10	ns	1.0 to 3.5V
T_{CL2CL1}	CLKOUT Fall Time		10		10		10	ns	3.5 to 1.0V

NOTES:
1. T_{CLCK} and T_{CHCK} (CLKIN Low and High times) should not have a duration less than 40% of T_{CKIN}
2. Tested under worst case conditions: V_{CC} = 5.5V (5.25V @ 16 MHz). T_A = 70°C.
3. Not Tested.
4. Tested under worst case conditions: V_{CC} = 4.5V (4.75V @ 16 MHz). T_A = 0°C.

CLOCK WAVEFORMS



270432-40

A. C. CHARACTERISTICS

READY, PERIPHERAL, AND QUEUE STATUS TIMINGS

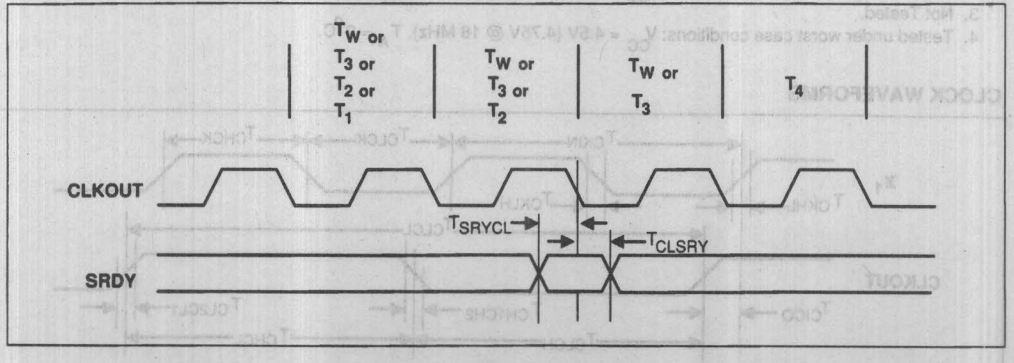
$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 READY AND PERIPHERAL TIMING REQUIREMENTS									
T_{SRYCL}	Synchronous Ready(SRDY) Transition Setup Time (1)	15		15		15		ns	
T_{CLSRY}	SRDY Transition Hold Time (1)	15		15		15		ns	
T_{ARYCH}	ARDY Resolution Transition Setup Time (2)	15		15		15		ns	
T_{CLARX}	ARDY Active Hold Time (1)	15		15		15		ns	
T_{ARYCHL}	ARDY Inactive Holding Time	15		15		15		ns	
T_{ARYLCL}	Asynchronous Ready (ARDY) Setup Time (1)	25		25		25		ns	
T_{INVCH}	INTx, NMI, $\overline{TEST}$/BUSY, TMR IN Setup Time (2)	15		15		15		ns	
T_{INVCL}	DRQ0, DRQ1 Setup Time(2)	15		15		15		ns	
80C188 PERIPHERAL AND QUEUE STATUS TIMING RESPONSES									
T_{CLTMV}	Timer Output Delay		40		33		27	ns	
T_{CHQSV}	Queue Status Delay		37		32		30	ns	

NOTES:
1. To guarantee proper operation.
2. To guarantee recognition at clock edge.

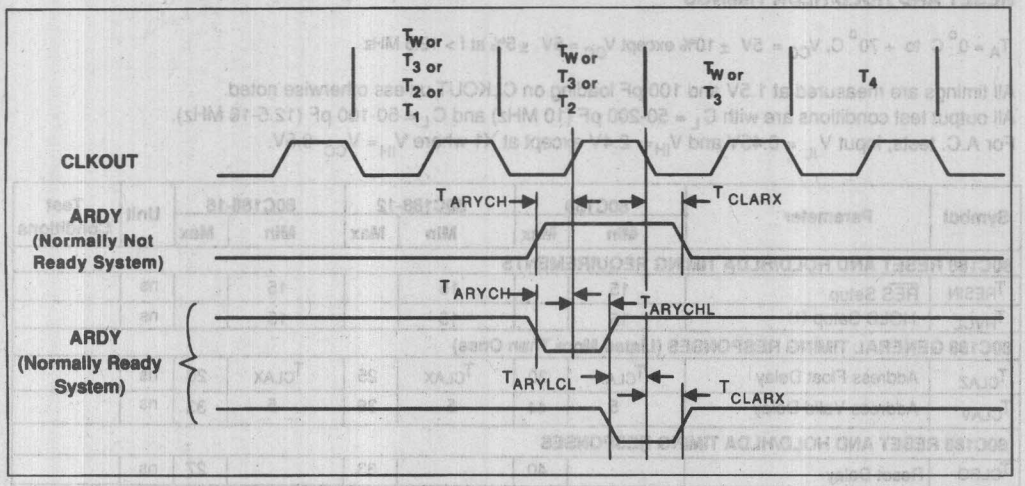
SYNCHRONOUS READY (SRDY) WAVEFORMS



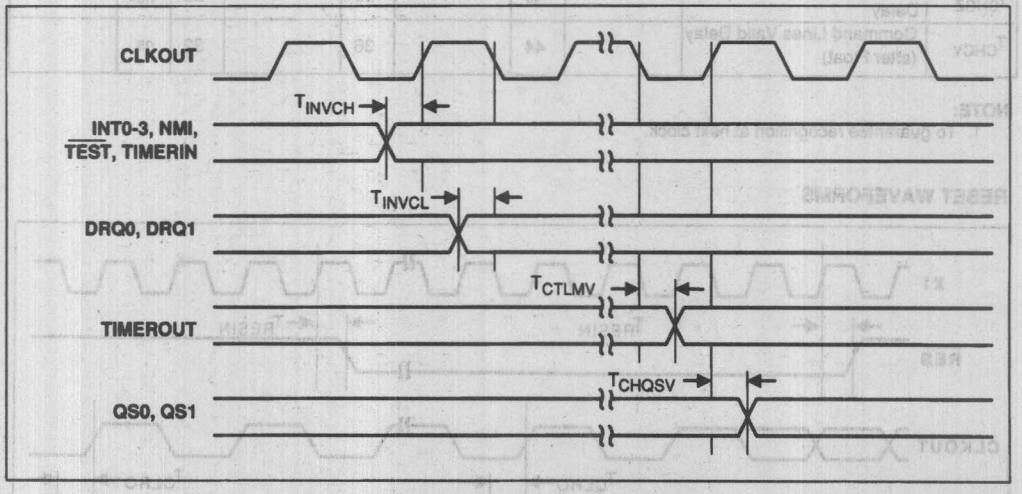
270432-41

A. C. CHARACTERISTICS

ASYNCHRONOUS READY (ARDY) WAVEFORMS



PERIPHERAL AND QUEUE STATUS WAVEFORMS



270432-42

A. C. CHARACTERISTICS

RESET AND HOLD/HLDA TIMINGS

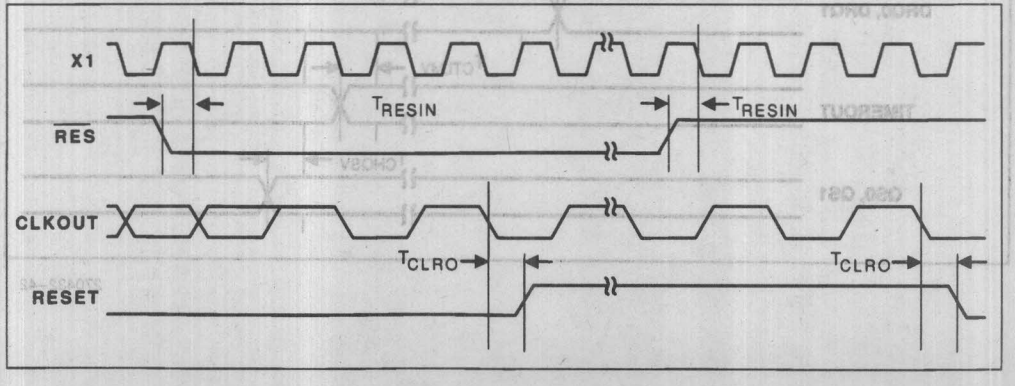
$T_A = 0^\circ C$ to $+70^\circ C$, $V_{CC} = 5V \pm 10\%$ except $V_{CC} = 5V \pm 5\%$ at $f > 12.5$ MHz

All timings are measured at 1.5V and 100 pF loading on CLKOUT unless otherwise noted.
All output test conditions are with C_L = 50-200 pF (10 MHz) and C_L = 50-100 pF (12.5-16 MHz).
For A.C. tests, input V_{IL} = 0.45V and V_{IH} = 2.4V except at X1 where $V_{IH} = V_{CC} - 0.5V$.

Symbol	Parameter	80C188		80C188-12		80C188-16		Unit	Test Conditions
		Min	Max	Min	Max	Min	Max		
80C188 RESET AND HOLD/HLDA TIMING REQUIREMENTS									
T_{RESIN}	$\overline{RES}$ Setup	15		15		15		ns	
T_{HVCL}	HOLD Setup (1)	15		15		15		ns	
80C188 GENERAL TIMING RESPONSES (Listed More Than Once)									
T_{CLAZ}	Address Float Delay	T_{CLAX}	30	T_{CLAX}	25	T_{CLAX}	20	ns	
T_{CLAV}	Address Valid Delay	5	44	5	36	5	33	ns	
80C188 RESET AND HOLD/HLDA TIMING RESPONSES									
T_{CLRO}	Reset Delay		40		33		27	ns	
T_{CLHAV}	HLDA Valid Delay	3	40	3	33	3	25	ns	
T_{CHCZ}	Command Lines Float Delay		40		33		28	ns	
T_{CHCV}	Command Lines Valid Delay (after Float)		44		36		32	ns	

NOTE:
1. To guarantee recognition at next clock.

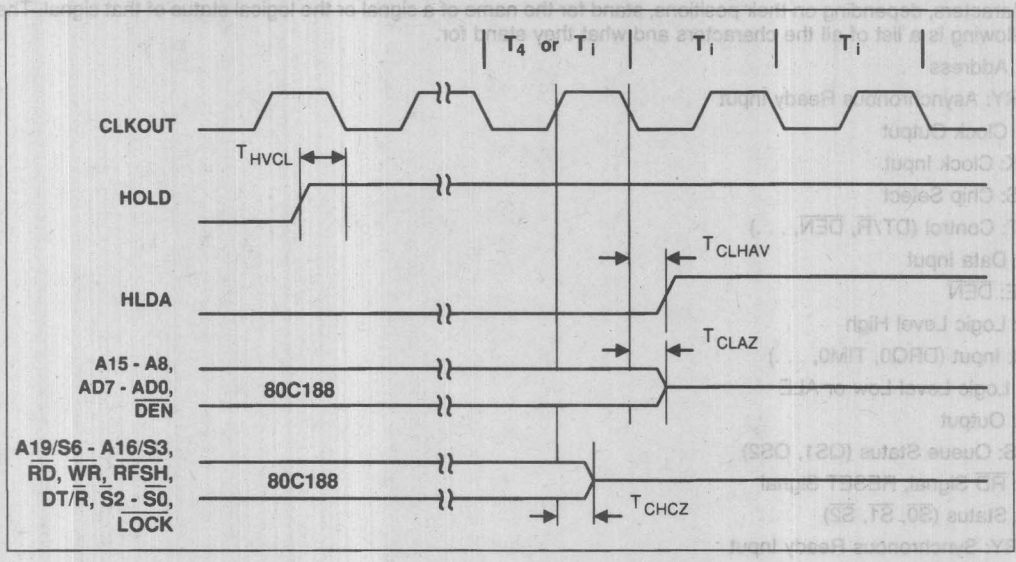
RESET WAVEFORMS



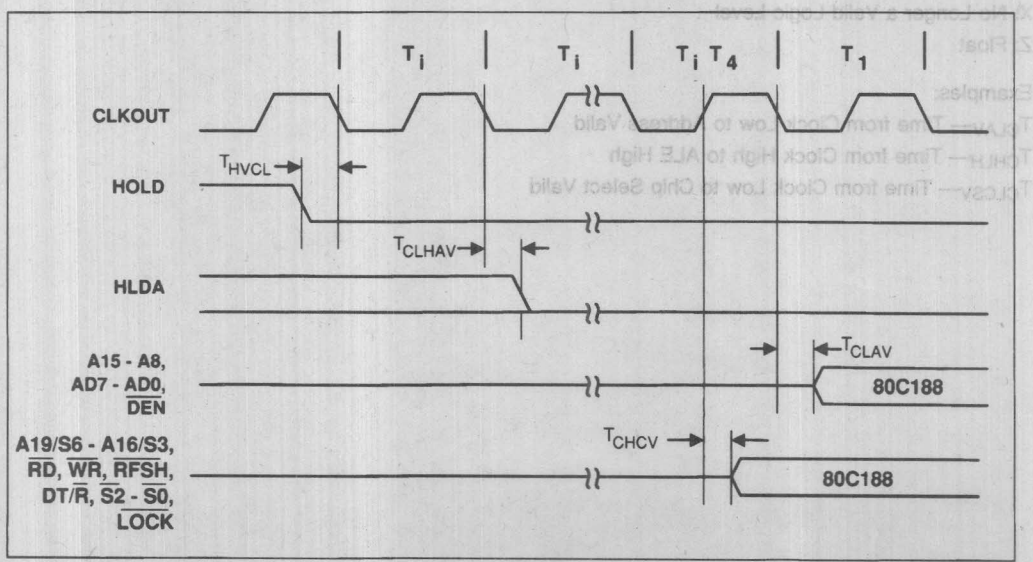
270432-43

A. C. CHARACTERISTICS

HOLD/HLDA WAVEFORMS (Entering Hold)



HOLD/HLDA WAVEFORMS (Leaving Hold)



270432-44

EXPLANATION OF THE AC SYMBOLS

Each timing symbol has from 5 to 7 characters. The first character is always a "T" (stands for time). The other characters, depending on their positions, stand for the name of a signal or the logical status of that signal. The following is a list of all the characters and what they stand for.

A: Address
ARY: Asynchronous Ready Input
C: Clock Output
CK: Clock Input
CS: Chip Select
CT: Control (DT/$\overline{R}$, $\overline{DEN}$, . . .)
D: Data Input
DE: $\overline{DEN}$
H: Logic Level High
IN: Input (DRQ0, TIM0, . . .)
L: Logic Level Low or ALE
O: Output
QS: Queue Status (QS1, QS2)
R: $\overline{RD}$ Signal, RESET Signal
S: Status ($\overline{S0}$, $\overline{S1}$, $\overline{S2}$)
SRY: Synchronous Ready Input
V: Valid
W: WR Signal
X: No Longer a Valid Logic Level
Z: Float

Examples:

T_{CLAV}— Time from Clock Low to Address Valid
T_{CHLH}— Time from Clock High to ALE High
T_{CLCSV}— Time from Clock Low to Chip Select Valid

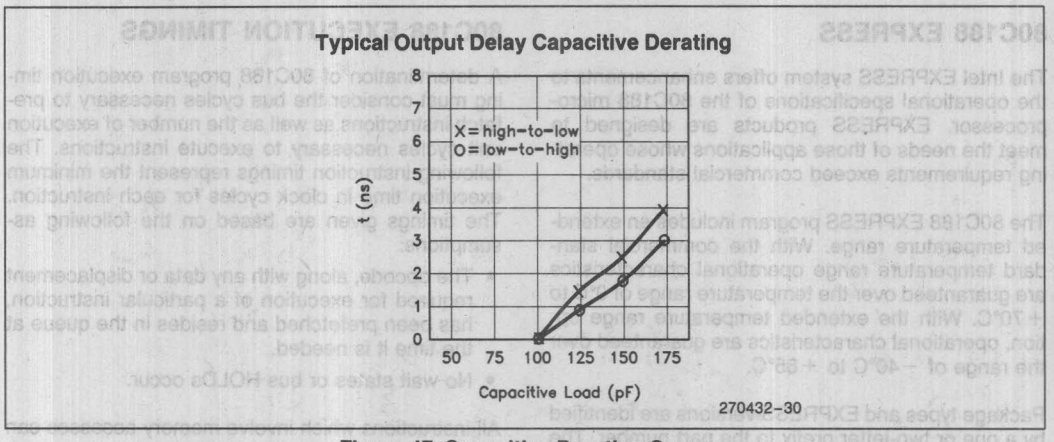


Figure 47. Capacitive Derating Curve

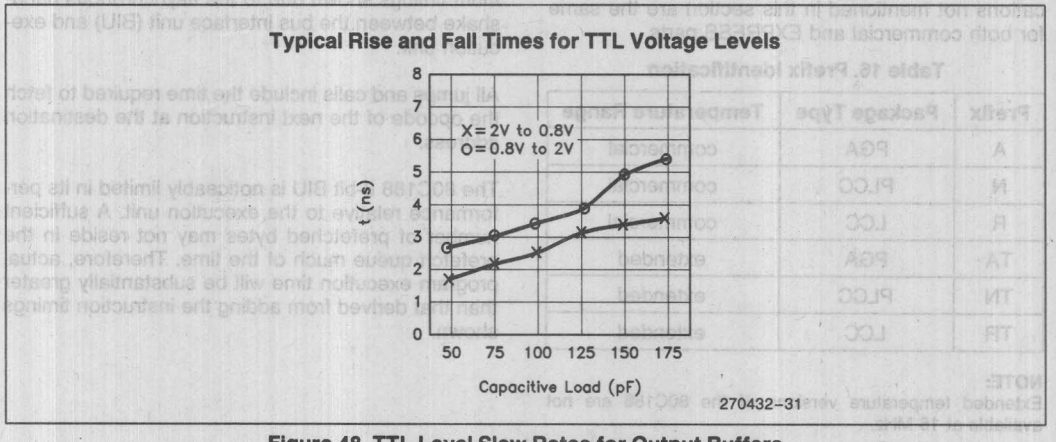


Figure 48. TTL Level Slew Rates for Output Buffers

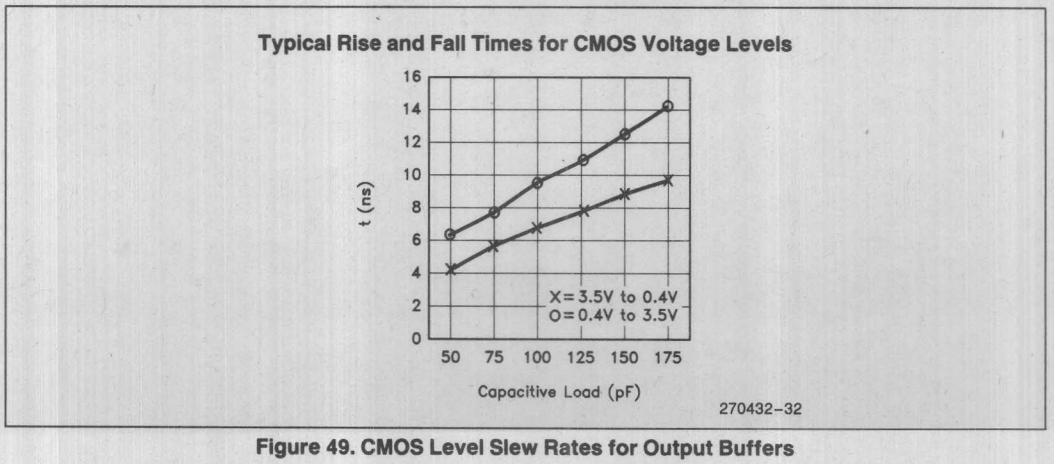


Figure 49. CMOS Level Slew Rates for Output Buffers

80C188 EXPRESS

The Intel EXPRESS system offers enhancements to the operational specifications of the 80C188 microprocessor. EXPRESS products are designed to meet the needs of those applications whose operating requirements exceed commercial standards.

The 80C188 EXPRESS program includes an extended temperature range. With the commercial standard temperature range operational characteristics are guaranteed over the temperature range of 0°C to +70°C. With the extended temperature range option, operational characteristics are guaranteed over the range of −40°C to +85°C.

Package types and EXPRESS versions are identified by a one or two-letter prefix to the part number. The prefixes are listed in Table 16. All AC and DC specifications not mentioned in this section are the same for both commercial and EXPRESS parts.

Table 16. Prefix Identification

Prefix	Package Type	Temperature Range
A	PGA	commercial
N	PLCC	commercial
R	LCC	commercial
TA	PGA	extended
TN	PLCC	extended
TR	LCC	extended

NOTE:
Extended temperature versions of the 80C188 are not available at 16 MHz.

80C188 EXECUTION TIMINGS

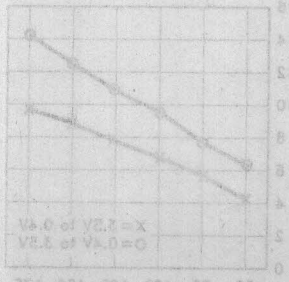
A determination of 80C188 program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDs occur.

All instructions which involve memory accesses can require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the bus interface unit (BIU) and execution unit.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

The 80C188 8-bit BIU is noticeably limited in its performance relative to the execution unit. A sufficient number of prefetched bytes may not reside in the prefetch queue much of the time. Therefore, actual program execution time will be substantially greater than that derived from adding the instruction timings shown.



INSTRUCTION SET SUMMARY

Function	Format				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1000100w	mod reg r/m			2/12*	
Register/memory to register	1000101w	mod reg r/m			2/9*	
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1	12/13	8/16-bit
Immediate to register	1011w reg	data	data if w=1		3/4	8/16-bit
Memory to accumulator	1010000w	addr-low	addr-high		8*	
Accumulator to memory	1010001w	addr-low	addr-high		9*	
Register/memory to segment register	10001110	mod 0 reg r/m			2/13	
Segment register to register/memory	10001100	mod 0 reg r/m			2/15	
PUSH = Push:						
Memory	11111111	mod 110 r/m			20	
Register	01010 reg				14	
Segment register	000reg110				13	
Immediate	011010s0	data	data if s=0		14	
PUSHA = Push All	01100000				68	
POP = Pop:						
Memory	10001111	mod 000 r/m			24	
Register	01011 reg				14	
Segment register	000reg111	(reg≠01)			12	
POPA = Pop All	01100001				83	
XCHG = Exchange:						
Register/memory with register	1000011w	mod reg r/m			4/17*	
Register with accumulator	10010 reg				3	
IN = Input from:						
Fixed port	1110010w	port			10*	
Variable port	1110110w				8*	
OUT = Output to:						
Fixed port	1110011w	port			9*	
Variable port	1110111w				7*	
XLAT = Translate byte to AL	11010111				15	
LEA = Load EA to register	10001101	mod reg r/m			6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)		26	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)		26	
LAHF = Load AH with flags	10011111				2	
SAHF = Store AH into flags	10011110				3	
PUSHF = Push flags	10011100				13	
POPF = Pop flags	10011101				12	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

***NOTE:**
Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
DATA TRANSFER (Continued)						
SEGMENT = Segment Override:						
CS	00101110				2	
SS	00110110				2	
DS	00111110				2	
ES	00100110				2	
ARITHMETIC						
ADD = Add:						
Reg/memory with register to either	000000dw	mod reg r/m			3/10*	
Immediate to register/memory	100000sw	mod 000 r/m	data	data if s w=01	4/16*	
Immediate to accumulator	0000010w	data	data if w=1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	000100dw	mod reg r/m			3/10*	
Immediate to register/memory	100000sw	mod 010 r/m	data	data if s w=01	4/16*	
Immediate to accumulator	0001010w	data	data if w=1		3/4	8/16-bit
INC = Increment:						
Register/memory	1111111w	mod 000 r/m			3/15*	
Register	01000 reg				3	
SUB = Subtract:						
Reg/memory and register to either	001010dw	mod reg r/m			3/10*	
Immediate from register/memory	100000sw	mod 101 r/m	data	data if s w=01	4/16*	
Immediate from accumulator	0010110w	data	data if w=1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	000110dw	mod reg r/m			3/10*	
Immediate from register/memory	100000sw	mod 011 r/m	data	data if s w=01	4/16*	
Immediate from accumulator	0001110w	data	data if w=1		3/4	8/16-bit
DEC = Decrement						
Register/memory	1111111w	mod 001 r/m			3/15*	
Register	01001 reg				3	
CMP = Compare:						
Register/memory with register	0011101w	mod reg r/m			3/10*	
Register with register/memory	0011100w	mod reg r/m			3/10*	
Immediate with register/memory	100000sw	mod 111 r/m	data	data if s w=01	3/10*	
Immediate with accumulator	0011110w	data	data if w=1		3/4	8/16-bit
NEG = Change sign register/memory	1111011w	mod 011 r/m			3/10*	
AAA = ASCII adjust for add	00110111				8	
DAA = Decimal adjust for add	00100111				4	
AAS = ASCII adjust for subtract	00111111				7	
DAS = Decimal adjust for subtract	00101111				4	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

***NOTE:**
Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
ARITHMETIC (Continued)			
MUL = Multiply (unsigned):	1111011w | mod 100 r/m		
Register-Byte		26–28	
Register-Word		35–37	
Memory-Byte		32–34	
Memory-Word		41–43*	
IMUL = Integer multiply (signed):	1111011w | mod 101 r/m		
Register-Byte		25–28	
Register-Word		34–37	
Memory-Byte		31–34	
Memory-Word		40–43*	
IMUL = Integer Immediate multiply (signed)	011010s1 | mod reg r/m | data | data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1111011w | mod 110 r/m		
Register-Byte		29	
Register-Word		38	
Memory-Byte		35	
Memory-Word		44*	
IDIV = Integer divide (signed):	1111011w | mod 111 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67*	
AAM = ASCII adjust for multiply	11010100 | 00001010	19	
AAD = ASCII adjust for divide	11010101 | 00001010	15	
CBW = Convert byte to word	10011000	2	
CWD = Convert word to double word	10011001	4	
LOGIC			
Shift/Rotate Instructions:			
Register/Memory by 1	1101000w | mod TTT r/m	2/15	
Register/Memory by CL	1101001w | mod TTT r/m	5+n/17+n	
Register/Memory by Count	1100000w | mod TTT r/m | count	5+n/17+n	
	TTT Instruction 000 ROL 001 ROR 010 RCL 011 RCR 100 SHL/SAL 101 SHR 111 SAR		
AND = **And:**			
Reg/memory and register to either	001000dw | mod reg r/m	3/10*	
Immediate to register/memory	1000000w | mod 100 r/m | data | data if w=1	4/16*	
Immediate to accumulator	0010010w | data | data if w=1	3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

***NOTE:**
Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
LOGIC (Continued)						
TEST = And function to flags, no result:						
Register/memory and register	1000010w	mod reg r/m			3/10*	
Immediate data and register/memory	1111011w	mod 000 r/m	data	data if w=1	4/10*	
Immediate data and accumulator	1010100w	data	data if w=1		3/4	8/16-bit
OR = Or:						
Reg/memory and register to either	000010dw	mod reg r/m			3/10*	
Immediate to register/memory	1000000w	mod 001 r/m	data	data if w=1	4/16*	
Immediate to accumulator	0000110w	data	data if w=1		3/4	8/16-bit
XOR = Exclusive or:						
Reg/memory and register to either	001100dw	mod reg r/m			3/10*	
Immediate to register/memory	1000000w	mod 110 r/m	data	data if w=1	4/16*	
Immediate to accumulator	0011010w	data	data if w=1		3/4	8/16-bit
NOT = Invert register/memory	1111011w	mod 010 r/m			3/10*	
STRING MANIPULATION						
MOVS = Move byte/word	1010010w				14*	
CMPS = Compare byte/word	1010011w				22*	
SCAS = Scan byte/word	1010111w				15*	
LODS = Load byte/wd to AL/AX	1010110w				12*	
STOS = Store byte/wd from AL/AX	1010101w				10*	
INS = Input byte/wd from DX port	0110110w				14	
OUTS = Output byte/wd to DX port	0110111w				14	
Repeated by count in CX (REP/ REPE/REPZ/REPNE/REPNZ)						
MOVS = Move string	11110010	1010010w			8+8n*	
CMPS = Compare string	1111001z	1010011w			5+22n*	
SCAS = Scan string	1111001z	1010111w			5+15n*	
LODS = Load string	11110010	1010110w			6+11n*	
STOS = Store string	11110010	1010101w			6+9n*	
INS = Input string	11110010	0110110w			8+8n*	
OUTS = Output string	11110010	0110111w			8+8n*	
CONTROL TRANSFER						
CALL = Call:						
Direct within segment	11101000	disp-low	disp-high		19	
Register/memory indirect within segment	11111111	mod 010 r/m			17/27	
Direct intersegment	10011010	segment offset			31	
		segment selector				
Indirect intersegment	11111111	mod 011 r/m	(mod ≠ 11)		54	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

***NOTE:**
Clock cycles shown for byte transfer. For word operations, add 4 clock cycles for all memory transfers.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
JMP = Unconditional jump:						
Short/long	11101011	disp-low			14	
Direct within segment	11101001	disp-low	disp-high		14	
Register/memory indirect within segment	11111111	mod 100 r/m			11/21	
Direct intersegment	11101010	segment offset			14	
		segment selector				
Indirect intersegment	11111111	mod 101 r/m	(mod ≠ 11)		34	
RET = Return from CALL:						
Within segment	11000011				20	
Within seg adding immed to SP	11000010	data-low	data-high		22	
Intersegment	11001011				30	
Intersegment adding immediate to SP	11001010	data-low	data-high		33	
JE/JZ = Jump on equal/zero	01110100	disp			4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100	disp			4/13	
JLE/JNG = Jump on less or equal/not greater	01111110	disp			4/13	
JB/JNAE = Jump on below/not above or equal	01110010	disp			4/13	
JBE/JNA = Jump on below or equal/not above	01110110	disp			4/13	
JP/JPE = Jump on parity/parity even	01111010	disp			4/13	
JO = Jump on overflow	01110000	disp			4/13	
JS = Jump on sign	01111000	disp			4/13	
JNE/JNZ = Jump on not equal/not zero	01110101	disp			4/13	
JNL/JGE = Jump on not less/greater or equal	01111101	disp			4/13	
JNLE/JG = Jump on not less or equal/greater	01111111	disp			4/13	
JNB/JAE = Jump on not below/above or equal	01110011	disp			4/13	
JNBE/JA = Jump on not below or equal/above	01110111	disp			4/13	
JNP/JPO = Jump on not par/par odd	01111011	disp			4/13	
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					19	
L = 1					29	
L > 1					26 + 20(n − 1)	
LEAVE = Leave Procedure	11001001				8	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
CONTROL TRANSFER (Continued)			
INT = Interrupt:			
Type specified	11001101 | type	47	
Type 3	11001100	45	if INT. taken/
INTO = Interrupt on overflow	11001110	48/4	if INT. not taken
IRET = Interrupt return	11001111	28	
BOUND = Detect value out of range	01100010 | mod reg r/m	33–35	
PROCESSOR CONTROL			
CLC = Clear carry	11111000	2	
CMC = Complement carry	11110101	2	
STC = Set carry	11111001	2	
CLD = Clear direction	11111100	2	
STD = Set direction	11111101	2	
CLI = Clear interrupt	11111010	2	
STI = Set interrupt	11111011	2	
HLT = Halt	11110100	2	
WAIT = Wait	10011011	6	if $\overline{TEST}$ = 0
LOCK = Bus lock prefix	11110000	2	
NOP = No Operation	10010000	3	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

REVISION HISTORY

The sections significantly revised since version -003 are:

Pin Description Table	Added note to $\overline{TEST}$ pin requiring proper RESET at power-up to configure pin as input.
	Renamed pin 44 to INT1/$\overline{SELECT}$ and pin 41 to INT3/$\overline{INTA1}$/IRQ to better describe their functions in Slave Mode.
Initialization and Processor Reset	Added reminder to drive $\overline{RES}$ pin LOW during power-up.
Read and Write Cycle Waveforms	Clarified applicability of T_{CLCSV} to latched A1 and A2 in footnotes.
Instruction Set Summary	Corrected clock count for ENTER instruction.
Slave Mode Operation	The three low order bits associated with vector generation and performing EOI are not alterable; however, the priority levels are programmable. This information is a clarification only.

The sections significantly revised since version -002 are:

Front Page	Deleted references to burn-in devices.
Local Bus Controller and Reset	Clarified effects of excessive loading on pins with internal pullup devices. Equivalent resistance no longer shown.
D.C. Characteristics	Renamed V_{CLI} to V_{IL1}. Renamed V_{CHI} to V_{IH3}. Changed V_{OH} (min) from 0.8 V_{CC} to V_{CC} − 0.5V. Changed I_{CC} (max) from 180 mA to 150 mA at 16 MHz, 150 mA to 120 mA at 12.5 MHz, and 120 mA to 100 mA at 10 MHz. Changed V_{CLO} (max) from 0.5V to 0.45V. Changed V_{CHO} (min) from 0.8 V_{CC} to V_{CC} − 0.5V. Clarified effect of excessive loading on pins with internal pullup devices.
Power Supply Current	Added equation and graph for maximum current.
A.C. Characteristics	Many timings changed (all listed in ns): T_{DVCL} (min) at 16 MHz from 10 to 15; T_{CLDX} (min) from 5 to 3; T_{CLAV} (max) at 10 MHz from 50 to 44; T_{CHCV} (max) from 45 to 44 at 10 MHz and from 37 to 36 at 12.5 MHz; T_{LHLL} (min) from T_{CLCL} − 30 to T_{CLCL} − 15; T_{LLAX} (min) at 10 MHz from T_{CHCL} − 20 to T_{CHCL} − 15; T_{CVCTV} (max) from 56 to 44 at 10 MHz, and from 47 to 37 at 12.5 MHz; T_{CVDEX} (max) from 56 to 44 at 10 MHz, 47 to 37 at 12.5 MHz, and from 35 to 31 at 16 MHz; T_{RHAV} (min) from T_{CLCL} − 40 at 10 MHz and T_{CLCL} − 20 at 12.5 MHz and 16 MHz to T_{CLCL} − 15 at all frequencies; T_{RLRH} (min) from 2 T_{CLCL} − 46 to 2 T_{CLCL} − 30 at 10 MHz, from 2 T_{CLCL} − 40 to 2 T_{CLCL} − 25 at 12.5 MHz, and T_{CLCL} − 30 to 2 T_{CLCL} − 25 at 16 MHz; T_{WLWH} (min) from 2 T_{CLCL} − 34 to 2 T_{CLCL} − 30 at 10 MHz, and 2 T_{CLCL} − 30 to 2 T_{CLCL} − 25 at 12.5 MHz, T_{AVLL} (min) from T_{CLCH} − 19 to T_{CLCH} − 18 at 10 MHz; T_{CLSH} (max) at 10 MHz from 50 to 46; T_{CLTMV} (max) from 48 to 40 at 10 MHz; 40 to 33 at 12.5 MHz, and 30 to 27 at 16 MHz; T_{CLRO} (max) from 48 to 40 at 10 MHz, 40 to 33 at 12.5 MHz, and 37 to 27 at 16 MHz; T_{CHQSV} (max) from 28 to 37 at 10 MHz, 28 to 32 at 12.5 MHz, and 25 to 30 at 16 MHz; T_{CHDX} (min) from 5 to 10; T_{CLLV} (max) at 10 MHz from 45 to 40 and at 12.5 MHz from 40 to 37; T_{CLCSV} (max) from 45 to 42 at 10 MHz; T_{CHCSX} (max) from 32 to 35 at 10 MHz, 28 to 30 at 12.5 MHz, and 23 to 25 at 16 MHz; and T_{CH1CH2} and T_{CL2CL1} (max) at 16 MHz from 8 to 10. Added new timings for T_{WHDEX}, T_{RHLH}, and T_{WHLH}. Established minimum timing for T_{CLCSV}.

Timing Waveforms	Section rearranged to show waveforms on same or facing page relative to corresponding tabular data. T_{CLSRY} drawn to same clock edge as T_{SRYCL}. Drawing changed to indicate one less clock between HOLD inactive and HLDA inactive.
Specification Level Markings	New section.

The sections significantly revised since version -001 are:

LCC Contact Diagram	Corrections made to upper address pins.
Pin Description Table	Various descriptions rewritten for clarity.
Interrupt Vector Table	Redrawn for clarity.
ESC Opcode Exception Description	Note added concerning ESC trap.
Oscillator Configurations	Deleted drive of X2 with inverted X1.
RESET Logic	Deleted paragraph concerning setup times for synchronization of multiple processors.
Local Bus Arbitration	Added description of HLDA when a refresh cycle is pending.
Local Bus Controller and Reset	Added description of pullup devices for appropriate pins.
DMA Controller	Added reminder to initialize transfer count registers and pointer registers.
Timers	Added reminder to initialize count registers.
DRAM Refresh Addresses	Refresh address counter described in figure.
D.C. Characteristics	V_{IH2} indicated for SRDY, ARDY. I_{CC} (max.) now indicated for all devices.
Power Supply Current	Typical I_{CC} indicated.
A.C. Characteristics	Input V_{IH} test condition at X1 added. T_{CLDOX}, T_{CVCTV}, T_{CVCTX}, T_{CLHAV} and T_{CLLV} minimums reduced from 5 ns to 3 ns. T_{CLCH} min. and T_{CHCL} min. relaxed by 2 ns. Added reminder that T_{SRYCL} and T_{CLSRY} must be met.
Explanation of the A.C. Symbols	New section.
Major Cycle Timing Waveforms	T_{DXDL} indicated in Read Cycle. T_{CLRO} indicated.
Rise/Fall Times and Capacitive Derating Curves	New Figures added.
Instruction Set Summary	ESC deleted.

SPECIFICATION LEVEL MARKINGS

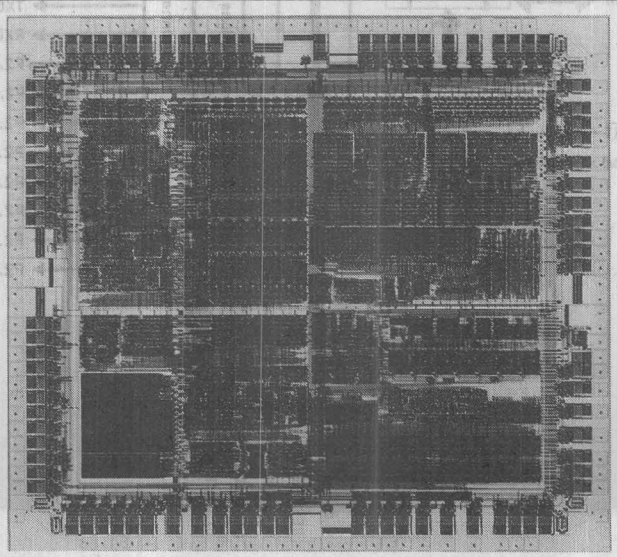
Current 80C188 devices bear backside lot code information consisting of seven digits followed by letters. The second, third, and fourth digits comprise a manufacturing data code. This preliminary data sheet applies only to 80C188 devices with a date code corresponding to week 25 of 1989 (backside markings x925xxx XXX) or later.

80C188EB-16, -13, -8
16-BIT HIGH-INTEGRATION EMBEDDED PROCESSOR

- Full Static Operation
- True CMOS Inputs and Outputs
- −40°C to +85°C Operating Temperature Range
- Low System Cost 8-Bit Interface

- **Integrated Feature Set**
  - Low-Power Static CPU Core
  - Two Independent UARTs each with an Integral Baud Rate Generator
  - Two 8-Bit Multiplexed I/O Ports
  - Programmable Interrupt Controller
  - Three Programmable 16-Bit Timer/Counters
  - Clock Generator
  - Ten Programmable Chip Selects with Integral Wait-State Generator
  - Memory Refresh Control Unit
  - System Level Testing Support (ONCE™ Mode)
- **Direct Addressing Capability to 1 Mbyte Memory and 64 Kbyte I/O**
- **Speed Versions Available:**
  - 16 MHz (80C188EB-16)
  - 13 MHz (80C188EB-13)
  - 8 MHz (80C188EB-8)
- **Low-Power Operating Modes:**
  - Idle Mode Freezes CPU Clocks but keeps Peripherals Active
  - Powerdown Mode Freezes All Internal Clocks
- **Complete System Development Support**
  - ASM86 Assembler, PL/M 86, Pascal 86, Fortran 86, C-86, and System Utilities
  - In-Circuit Emulator (ICE™-188EB)
- **Available In:**
  - 80-Pin Quad Flat Pack (S80C188EB)
  - 84-Pin Plastic Leaded Chip Carrier (N80C188EB)

The 80C188EB is a second generation CHMOS High-Integration microprocessor. It has features that are new to the 80C188 family and include a STATIC CPU core, an enhanced Chip Select decode unit, two independent Serial Channels, I/O ports, and the capability of Idle or Powerdown low power modes.



270885–36

December 1990
Order Number: 270885-001

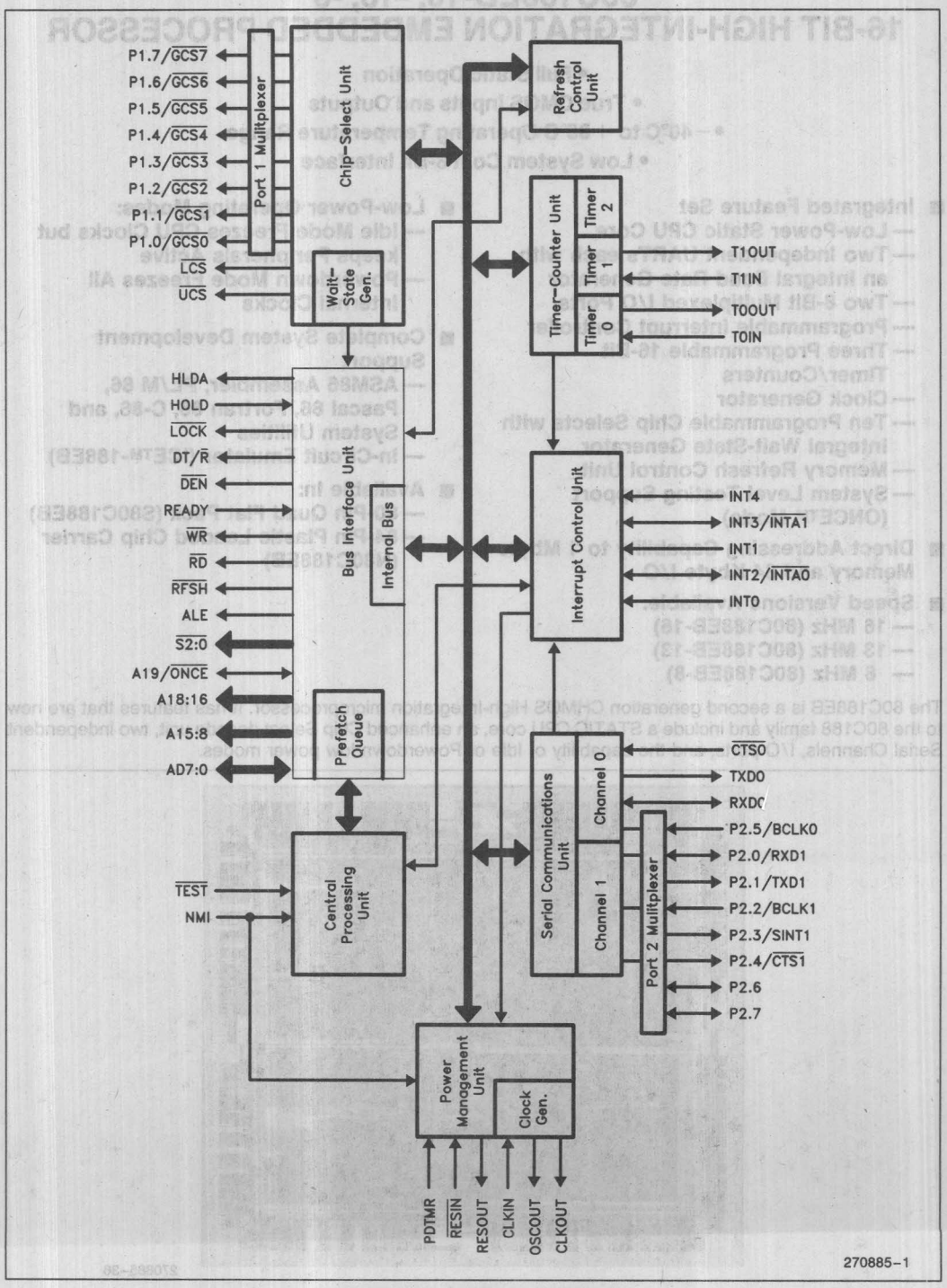


Figure 1. 80C188EB Block Diagram

INTRODUCTION

The 80C188EB is the first product in a new generation of low-power, high-integration microprocessors. It enhances the existing 186 family by offering new features and new operating modes. The 80C188EB is object code compatible with the 80C186/80C188 microprocessors. The 80C188EB has an 8-bit external data bus but still retains a 16-bit internal bus. An 8-bit external bus reduces system cost by requiring that only single byte-wide memories be used.

The feature set of the 80C188EB meets the needs of low power, space critical applications. Low-Power applications benefit from the static design of the CPU core and the integrated peripherals. Minimum current consumption is achieved by providing a Powerdown mode that halts operation of the device, and freezes the clock circuits. Peripheral design enhancements ensure that non-initialized peripherals consume little current.

Space critical applications benefit from the integration of commonly used system peripherals. Two serial channels are provided for services such as diagnostics, inter-processor communication, modem interface, terminal display interface, and many others. A flexible chip select unit simplifies memory and peripheral interfacing. The interrupt unit provides sources for up to 129 external interrupts and will prioritize these interrupts with those generated from the on-chip peripherals. Three general purpose timer/counters and sixteen multiplexed I/O port pins round out the feature set of the 80C188EB.

OVERVIEW

Figure 1 shows a block diagram of the 80C188EB. The Execution Unit (EU) is an enhanced 8088 CPU core that includes: dedicated hardware to speed up effective address calculations, enhance execution speed for multiple-bit shift and rotate instructions and for multiply and divide instructions, string move instructions that operate at full bus bandwidth, ten new instruction, and full Static operation. The Bus Interface Unit (BIU) is the same as that found on the original 188 family products, except the queue-status mode has been deleted and buffer interface control has been changed to ease system design timings. An independent internal bus is used to allow communication between the BIU and internal peripherals.

80C188EB Core Architecture

REGISTER SET

The 8086, 8088, 80186, 80188, 80C186, and 80C188 all contain the same basic set of registers, instructions, and addressing modes. The 80C188EB is upward compatible with all of these microprocessors.

The 80C188EB base architecture has fourteen 16-bit registers as shown in Figure 2. There are eight general purpose registers which may be used for arithmetic and logic operands. Four of these registers (AX, BX, CX, and DX) can be used as 16-bit registers or split into pairs of separate 8-bit registers. The other four registers (BP, SI, DI, and SP) may also be used to determine offset addresses of operands in memory. These registers may contain base addresses or indexes to particular locations within a segment. The addressing mode selects the specific registers for operand and address calculations.

Another four 16-bit registers (CS, DS, ES, SS) select the segments of memory that are immediately addressable for code, stack, and data. There are two remaining special purpose registers (IP and F) that record or alter certain aspects of the 80C188EB processor state.

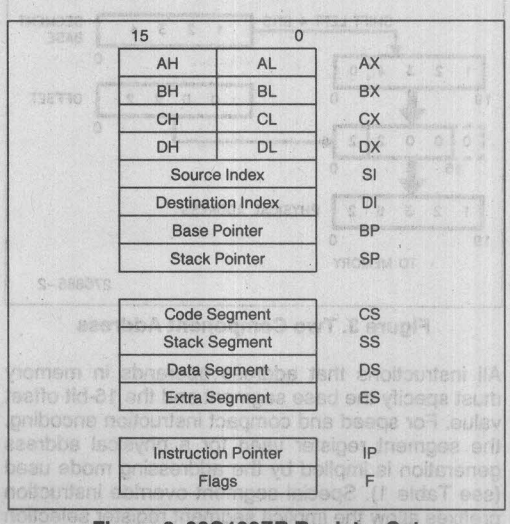


Figure 2. 80C188EB Register Set

INSTRUCTION SET

The instruction set is divided into seven categories: data transfer, arithmetic, shift/rotate/logical, string manipulation, control transfer, high-level instructions, and processor control. These categories are summarized in Figure 4.

An 80C188EB instruction can reference anywhere from zero to several operands. An operand can reside in a register, in the instruction itself, or in memory.

MEMORY ORGANIZATION

Memory is organized in sets of segments. Each segment is a linear contiguous sequence of up to 64K (2^{16}) 8-bit bytes. Memory is addressed using a two-component address (a pointer) that consists of a 16-bit base segment and a 16-bit offset. The 16-bit base segment values are contained in one of four internal segment registers (code, data stack, extra). The physical address is calculated by shifting the base value left by four bits and adding the 16-bit offset value to yield a 20-bit physical address (see Figure 3). A 20-bit address allows for a 1 MByte address size.

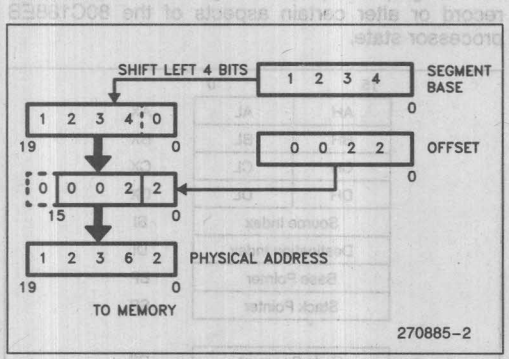


Figure 3. Two Component Address

All instructions that address operands in memory must specify the base segment and the 16-bit offset value. For speed and compact instruction encoding, the segment register used for a physical address generation is implied by the addressing mode used (see Table 1). Special segment override instruction prefixes allow the implicit segment register selection rules to be overridden for special cases. The stack, data, and extra segments may coincide for simple programs.

Table 1. Segment Register Selection Rules

Memory Reference Needed	Segment Register Used	Implicit Segment Selection Rule
Instructions	Code (CS)	Instruction prefetch and immediate data
Stack	Stack (SS)	All stack pushes and pops; any memory references which use the BP register as a base
External	Extra (ES)	All String instruction references which use the DI register as an index
Local Data	Data (DS)	All other data references

ADDRESSING MODES

The 80C188EB provides eight categories of addressing modes to specify operands. Two addressing modes are provided for instructions that operate on register or immediate operands:

- *Register Operand Mode:* The operand is located in one of the 8- or 16-bit general registers.
- *Immediate Operand Mode:* The operand is included in the instruction.

Six modes are provided to specify the location of an operand in a memory segment. A memory operand address consists of two 16-bit components: a segment base and an offset. The segment base is supplied by a 16-bit segment register either implicitly chosen by the addressing mode or explicitly chosen by a segment override prefix. The offset, also called the effective address, is calculated by summing any combination of the following three address elements:

- the *displacement* (an 8- or 16-bit immediate value contained in the instruction);
- the *base* (contents of either the BX or BP base registers); and
- the *index* (contents of either the SI or DI index registers).

GENERAL PURPOSE

MOV
PUSH
POP
PUSHA
POPA
XCHG
XLAT

INPUT/OUTPUT

IN
OUT

ADDRESS OBJECT

LEA
LDS
LES

FLAG TRANSFER

LAHF
SAHF
PUSHF
POPF

ADDITION

ADD
INC
AAA
DAA

SUBSTRACTION

SUB
SBB
DEC
NEG
CMP
AAS
DAS

MULTIPLICATION

MUL
IMUL
AAM

DIVISION

DIV
IDIV
AAD
CBW
CWD

STRING OPERATIONS

MOVS
INS
OUTS
CMPS
SCAS
LODS
STOS
REP
REPE/REPZ
REPNE/REPNZ

LOGICALS

NOT
AND
OR
XOR
TEST

SHIFTS

SHL/SAL
SHR
SAR

ROTATES

ROL
ROR
RCL
RCR

FLAG OPERATIONS

STC
CLC
CMC
STD
CLD
STI
CLI

EXTERNAL SYNCHRONIZATION

HLT
WAIT
LOCK

NO OPERATION

NOP

HIGH LEVEL INSTRUCTIONS

ENTER
LEAVE
BOUND

CONDITIONAL TRANSFERS

JA/JNBE
JAE/JNB
JB/JNAE
JBE/JNA
JC
JE/JZ
JG/JNLE
JGE/JNL
JL/JNGE
JLE/JNG
JNC
JNE/JNZ
JNO
JNP/JP0
JNS
JO
JP/JPE
JS

UNCONDITIONAL TRANSFERS

CALL
RET
JMP

ITERATION CONTROLS

LOOP
LOOPE/LOOPZ
LOOPNE/LOOPNZ
JCXZ

INTERRUPTS

INT
INTO
IRET

Figure 4. 80C188EB Instruction Set

Any carry out from the 16-bit addition is ignored. 8-bit displacements are sign extended to 16-bit values.

Combinations of these three address elements define the six memory addressing modes, described below.

- *Direct Mode:* The operand's offset is contained in the instruction as an 8- or 16-bit displacement element.
- *Register Indirect Mode:* The operand's offset is in one of the registers SI, DI, BX, or BP.
- *Based Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of a base register (BX or BP).
- *Indexed Mode:* The operand's offset is the sum of an 8- or 16-bit displacement and the contents of an index register (SI or DI).
- *Based Indexed Mode:* The operand's offset is the sum of the contents of a base register and an index register.
- *Based Indexed Mode with Displacement:* The operand's offset is the sum of a base register's contents, an index register's contents, and an 8- or 16-bit displacement.

DATA TYPES

The 80C188EB directly supports the following data types:

- *Integer:* A signed binary numeric value contained in an 8-bit byte or 16-bit word. All operations assume a 2's complement representation. Signed 32- and 64-bit integers are supported using the 80C187 Numerics Coprocessor.
- *Ordinal:* An unsigned binary numeric value contained in an 8-bit byte or 16-bit word.
- *Pointer:* A 16- or 32-bit quantity, composed of a 16-bit offset component, or a 16-bit segment base component and a 16-bit offset component.
- *String:* A contiguous sequence of bytes or words. A string may contain from 1 Kbyte to 64 Kbytes.
- *ASCII:* A byte representation of alphanumeric and control characters using the ASCII standard of character representation.
- *BCD:* A byte (unpacked) representation of the decimal digits 0–9.
- *Packed BCD:* A byte (packed) representation of two decimal digits (0–9). One digit is stored in each nibble (4 bits) of the byte.

In general, individual data elements must fit within defined segment limits.

INTERRUPTS

An interrupt transfers execution to a new program location. The old program address (CS:IP) and machine state (F) are saved on the stack to allow resumption of the interrupted program. Interrupts fall into three classes: hardware initiated, software (program) initiated, and instruction exception initiated. Hardware initiated interrupts occur in response to an external or internal input and are classified as nonmaskable or maskable.

Programs may cause an interrupt by executing the "INT" instruction. Instruction exceptions occur when an illegal opcode has been fetched into the queue and is read by the execution unit. Another type of exception can be generated when executing an "ESC" instruction.

For all cases except the "ESC" exception, the return address from an exception will point at the instruction immediately following the instruction causing the exception. The return address after an "ESC" exception will point back to the ESC instruction causing the exception, or to the segment override prefix immediately preceding the ESC instruction if the prefix was present.

A table containing up to 256 pointers defines the proper interrupt service routine for each interrupt. Interrupts 0–31 are reserved by Intel. Table 2 shows the 80C188EB predefined type and default priority levels. For each interrupt, an 8-bit vector (Vector Type) identifies the appropriate table entry. Multiplying the 8-bit vector by 4 defines the vector address. INT instructions contain or imply the vector type and allow access to all 256 interrupts.

Table 2. 80C188EB Interrupt Vectors

Interrupt Name	Vector Type	Vector Address	Default Priority	Related Instructions
Divide Error	0	00H	1	DIV, IDIV
Single Step Interrupt	1	04H	1A	All
Non-Maskable Interrupt	2	08H	1	INT 2 or NMI
One Byte Interrupt	3	0CH	1	INT
Interrupt on Overflow	4	10H	1	INT0
Array Bounds Check	5	14H	1	BOUND
Invalid OP-Code	6	18H	1	Illegal Inst
ESC OP-Code Interrupt	7	1CH	1	ESC OP-Codes
Timer 0 Interrupt	8	20H	2	
Reserved	9–11	24H–2CH		
INT0 Interrupt	12	30H	5	
INT1 Interrupt	13	34H	6	
INT2 Interrupt	14	38H	7	
INT3 Interrupt	15	3CH	8	
Reserved	16	40H		
INT4 Interrupt	17	44H	4	
Timer1 Interrupt	18	48H	2A	
Timer2 Interrupt	19	4CH	2B	
UART 0 Receive Interrupt	20	50H	3	
UART 0 Transmit Interrupt	21	54H	3A	
Reserved	22–31	58H–7CH		

BUS INTERFACE UNIT

The 80C188EB core incorporates a bus controller that generates local bus control signals. In addition, it employs a HOLD/HLDA protocol to share the local bus with other bus masters.

The bus controller is responsible for generating 20 bits of address, read and write strobes, bus cycle status information, and data (for write operations) information. It is also responsible for reading data off the local bus during a read operation. A ready input pin is provided to extend a bus cycle beyond the minimum four states (clocks).

A HOLD/HLDA protocol is provided by the local bus controller to allow multiple bus masters to share the same local bus. When the 80C188EB relinquishes control of the local bus, it floats certain bus control signals to allow another bus master to drive these pins directly. Refer to the Pin Description section to determine which pins the 80C188EB will float during a HOLD/HLDA bus exchange.

The 80C188EB local bus controller also generates two control signals ($\overline{DEN}$ and DT/$\overline{R}$) when interfacing to external transceiver chips. (Both $\overline{DEN}$ and DT/$\overline{R}$ are available on the N80C188EB device, only $\overline{DEN}$ is available on the S80C188EB device.) This capability allows the addition of transceivers for simple buffering of the mulitplexed address/data bus.

CLOCK GENERATOR

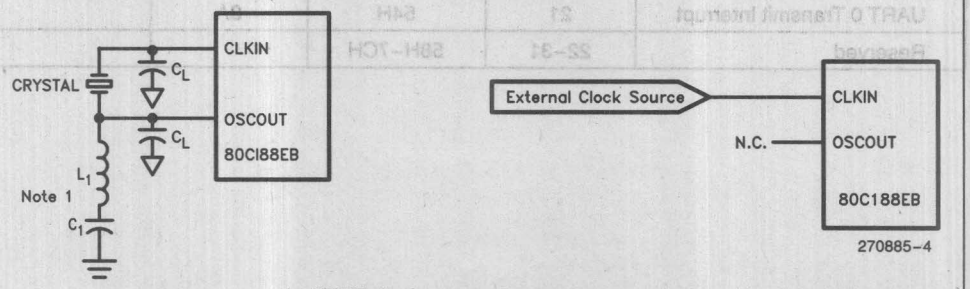
The 80C188EB provides an on-chip clock generator for both internal and external clock generation. The clock generator features a crystal oscillator, a divide-by-two counter, and two low-power operating modes.

The oscillator circuit is designed to be used with either a **parallel resonant** fundamental or third-overtone mode crystal network. Alternatively, the oscillator circuit may be driven from an external clock source. Figure 5 shows the various operating modes of the 80C188EB oscillator circuit.

The crystal or clock frequency chosen must be twice the required processor operating frequency due to the internal divide-by-two counter. This counter is used to drive all internal phase clocks and the external CLKOUT signal. CLKOUT is a 50% duty cycle processor clock and can be used to drive other system components. All A.C. timings are referenced to CLKOUT.

The following parameters are recommended when choosing a crystal:

Temperature Range:	Application Specific
ESR (Equivalent Series Resistance):	40Ω max
C0 (Shunt Capacitance of Crystal):	7.0 pF max
C1 (Load Capacitance):	20 pF ± 2 pF
Drive Level:	1 mW max



(A) Crystal Connection **(B) Clock Connection**

NOTE:
The L_1C_1 network is only required when using a third-overtone crystal.

Figure 5. 80C188EB Clock Configurations

80C188EB Peripheral Architecture

The 80C188EB has integrated several common system peripherals with a CPU core to create a compact, yet powerful system. The integrated peripherals are designed to be flexible and provide logical interconnections between supporting units (e.g., the interrupt control unit supports interrupt requests from the timer/counters or serial channels).

The list of integrated peripherals include:

- 7-Input Interrupt Control Unit
- 3-Channel Timer/Counter Unit
- 2-Channel Serial Communications Unit
- 10-Output Chip-Select Unit
- I/O Port Unit
- Refresh Control Unit
- Power Management Unit

The registers associated with each integrated peripheral are contained within a 128 x 16 register file called the Peripheral Control Block (PCB). The PCB can be located in either memory or I/O space on any 256 Byte address boundary. During bus cycles that access the PCB, the bus controller will signal the operation externally (i.e., the $\overline{RD}$, $\overline{WR}$, status, address, data, etc., lines will be driven as in a normal bus cycle). However, READY is ignored and the contents of the data bus during a read operation is ignored. When using any of the internal registers (AX, BX, etc.) as the source of data to be moved into a PCB register, it is recommended that a **byte** operation be specified. Since the 80C188EB retains a 16-bit internal bus architecture, all byte write operations to the PCB registers will result in word operation. If immediate data is used, then a word write must be specified.

The address of the PCB can overlap any of the memory or I/O regions programmed into the Chip Select Unit. In this case, the overlapped chip select will not go active when the PCB is read or written.

Figure 6 provides a list of the registers associated with the PCB. The Register Bit Summary individually lists all of the registers and identifies each of their programming attributes.

INTERRUPT CONTROL UNIT

The 80C188EB can receive interrupts from a number of sources, both internal and external. The interrupt control unit serves to merge these requests, on a priority basis, for individual service by the CPU. Each interrupt source can be independently masked by the Interrupt Control Unit (ICU) or all interrupts can be globally masked by the CPU.

Internal interrupt sources include the Timers and Serial channel 0. External interrupt sources come from the five input pins INT4:0. The NMI interrupt pin is not controlled by the ICU and is passed directly to the CPU. Although the Timer and Serial channel each have only one request input to the ICU, separate vector types are generated to service individual interrupts within the Timer and Serial channel units.

The 80C188EB ICU provides a mechanism for expanding the number of external interrupt sources. Two pairs of pins can be independently configured to support an external slave interrupt controller (82C59A). Each pair of external pins can be expanded to support 64 interrupts, making it possible for the 80C188EB to support a total of 129 external interrupts.

The ICU may be used in a polled mode if interrupts are undesirable. When polling, the processor disables interrupts and then polls the ICU whenever it is convenient.

TIMER/COUNTER UNIT

The 80C188EB Timer/Counter Unit (TCU) provides three 16-bit programmable timers. Two of these are highly flexible and are connected to external pins for control or clocking. A third timer is not connected to any external pins and can only be clocked internally. However, it can be used to clock the other two timer channels. The TCU can be used to count external events, time external events, generate non-repetitive waveforms, generate timed interrupts. etc.

Each timer has at least one 16-bit compare register and one 16-bit count register. Timers 0 and 1 each have an additional 16-bit compare register. The count register is incremented every fourth CPU clock cycle (internal clocking), every time Timer2 expires (Timers 0 and 1 only), or every Low-to-High transition on the timer input pin (Timers 0 and 1 only). The input clock to Timers 0 and 1 must not exceed one fourth the operating frequency of the 80C188EB. When the count register matches the value programmed into the compare register, several operations may happen.

All three timers can generate an interrupt when the compare register matches the value in the count register. Additionally, Timers 0 and 1 have an output pin that can change state or pulse when the compare condition occurs.

PCB Offset	Function
00H	Reserved
02H	End Of Interrupt
04H	Poll
06H	Poll Status
08H	Interrupt Mask
0AH	Priority Mask
0CH	In-Service
0EH	Interrupt Request
10H	Interrupt Status
12H	Timer Control
14H	Serial Control
16H	INT4
18H	INT0 Control
1AH	INT1 Control
1CH	INT2 Control
1EH	INT3 Control
20H	Reserved
22H	Reserved
24H	Reserved
26H	Reserved
28H	Reserved
2AH	Reserved
2CH	Reserved
2EH	Reserved
30H	Timer0 Count
32H	Timer0 Compare A
34H	Timer0 Compare B
36H	Timer0 Control
38H	Timer1 Count
3AH	Timer1 Compare A
3CH	Timer1 Compare B
3EH	Timer1 Control

PCB Offset	Function
40H	Timer2 Count
42H	Timer2 Compare
44H	Reserved
46H	Timer2 Control
48H	Reserved
4AH	Reserved
4CH	Reserved
4EH	Reserved
50H	Reserved
52H	Port0 Pin
54H	Port0 Control
56H	Port0 Latch
58H	Port1 Direction
5AH	Port1 Pin
5CH	Port1 Control
5EH	Port1 Latch
60H	Serial0 Baud
62H	Serial0 Count
64H	Serial0 Control
66H	Serial0 Status
68H	Serial0 RBUF
6AH	Serial0 TBUF
6CH	Reserved
6EH	Reserved
70H	Serial1 Baud
72H	Serial1 Count
74H	Serial1 Control
76H	Serial1 Status
78H	Serial1 RBUF
7AH	Serial1 TBUF
7CH	Reserved
7EH	Reserved

PCB Offset	Function
80H	GCS0 Start
82H	GCS0 Stop
84H	GCS1 Start
86H	GCS1 Stop
88H	GCS2 Start
8AH	GCS2 Stop
8CH	GCS3 Start
8EH	GCS3 Stop
90H	GCS4 Start
92H	GCS4 Stop
94H	GCS5 Start
96H	GCS5 Stop
98H	GCS6 Start
9AH	GCS6 Stop
9CH	GCS7 Start
9EH	GCS7 Stop
A0H	LCS Start
A2H	LCS Stop
A4H	UCS Start
A6H	UCS Stop
A8H	Relocation
AAH	Reserved
ACH	Reserved
AEH	Reserved
B0H	Refresh Base
B2H	Refresh Time
B4H	Refresh Control
B6H	Refresh Address
B8H	Power Control
BAH	Reserved
BCH	Step ID
BEH	Reserved

PCB Offset	Function
C0H	Reserved
C2H	Reserved
C4H	Reserved
C6H	Reserved
C8H	Reserved
CAH	Reserved
CCH	Reserved
CEH	Reserved
D0H	Reserved
D2H	Reserved
D4H	Reserved
D6H	Reserved
D8H	Reserved
DAH	Reserved
DCH	Reserved
DEH	Reserved
E0H	Reserved
E2H	Reserved
E4H	Reserved
E6H	Reserved
E8H	Reserved
EAH	Reserved
ECH	Reserved
EEH	Reserved
F0H	Reserved
F2H	Reserved
F4H	Reserved
F6H	Reserved
F8H	Reserved
FAH	Reserved
FCH	Reserved
FEH	Reserved

Figure 6. 80C188EB Peripheral Control Block Registers

Other timer programming options include:

- All three timers can be set to halt or continue after a compare match.
- Timers 0 and 1 can be reset or retriggered using their respective input pins.
- TCU registers can be read or written at any time.

SERIAL COMMUNICATIONS UNIT

The Serial Control Unit (SCU) of the 80C188EB contains two independent channels. Each channel is identical in operation except that only channel 0 is supported by the integrated interrupt controller (channel 1 has an external interrupt pin). Each channel has its own baud rate generator that is independent of the Timer/Counter Unit, and can be internally or externally clocked up to one half the 80C188EB operating frequency.

Each serial channel supports one synchronous and four asynchronous modes of operation and is compatible with the serial ports of the MCS®-51 and MCS®-96 family of products. Data field length can be 7-, 8-, or 9-bits with optional odd or even parity (generated and checked) and one stop bit (generated and checked). The 9-bit mode has an optional "addressing" feature to simplify interprocessor communication. Each serial port is doubled buffered in both transmit and receive operation (data can be read or written to a buffer register while data is shifted into or out of a shifting register, respectively).

A Clear-To-Send input pin can be programmed to prevent data transmission if the pin is sampled inactive. Serial channel 0 is supported by the integrated interrupt controller, providing separate receive and transmit vector types. Serial channel 1 has an external interrupt pin which OR's the receive and transmit interrupts. This external interrupt pin can be routed to either the external pins of the ICU, the NMI pin, or any other external system interrupt controller. Status bits are provided to allow polling of the serial channels if interrupts are not desired.

Independent baud rate generators are provided for each of the serial channels. For the asynchronous modes, the generator supplies an 8x baud clock to both the receive and transmit register logic. A 1x baud clock is provided in the synchronous mode.

Additional features of the SCU include:

- Framing error, receive buffer overrun error, and parity error detection.
- Break detect.
- Break send.

CHIP-SELECT UNIT

The 80C188EB Chip-Select Unit (CSU) integrates logic which provides up to ten programmable chip-selects to access both memories and peripherals. In addition, each chip-select can be programmed to automatically insert additional clocks (wait-states) into the current bus cycle and automatically terminate a bus cycle independent of the condition of the ready input pin.

Each of the chip-selects can be programmed to go active for either memory or I/O accesses. UCS is the only chip-select that is active after a reset and is enabled for memory addresses in the range 0FFC00H to 0FFFFFH (this allows a boot-ROM to be accessed using UCS). Every chip-select has a programmable start and stop register that defines the active region for the chip-select, and the ready characteristics for the region.

The start and stop address fields are 10 bits in length and are matched against the upper 10 bits of either the memory or I/O address. A 10-bit compare results in a granularity of 1 Kbytes for memory accesses and 64 bytes for I/O accesses. Each chip select can be disabled by programming its start address greater than its stop address or by clearing its enable bit.

Each chip-select can be programmed to automatically insert wait-states, and to control whether the external ready input is to be ignored or used. The 80C188EB bus controller will wait the programmed number of wait-states before the external ready pin can be used to extend or terminate the bus cycle.

Overlapping of chip-selects is allowed. However, each one that overlaps will go active. If any overlapping chip-select has been programmed to use external ready, the bus control unit will insert the least amount of programmed wait-states programmed before the external ready pin is used. If all overlapped chip-selects ignore external ready, the bus controller will insert the maximum number of programmed wait-states. Any chip-select that overlaps the Peripheral Control Block (PCB) will not go active for that portion of the address range allocated to the PCB.

The Generic Chip-Selects (GCS7:0) are multiplexed with an output only Port function. Any channel that is being used as a chip-select must be disabled as a port pin by correctly programming the port pin control registers (see the following section).

I/O PORT UNIT

The I/O Port Unit (IPU) on the 80C188EB supports two 8-bit channels of input, output, or input/output operation. Port 1 is multiplexed with the chip select pins and is output only. Most of Port 2 is multiplexed with the serial channel pins. Port 2 pins are limited to either an output or input function depending on the operation of the serial pin it is multiplexed with.

Two bits of Port 2 are not multiplexed with any other peripheral functions and can be used as either an input or an output function. A port direction register is used to define the function of the port pin. The output for these two pins are open drain.

Besides a direction register, each port channel has a port latch register, port pin register, and a port multiplexer control register.

REFRESH CONTROL UNIT

The Refresh Control Unit (RCU) automatically generates a periodic memory read bus cycle to keep dynamic or pseudo-static memory refreshed. A 9-bit counter controls the number of clocks between refresh requests.

A 12-bit address generator is maintained by the RCU and is presented on the A12:1 address lines during the refresh bus cycle. The address generator is incremented only after the refresh bus cycle is run. This ensures that all address combinations will be presented to the memory array even if the refresh bus cycle is not run before another request is generated. Address bits A19:13 are programmable to allow the refresh address block to be located on any 8 Kbyte boundary.

The chip-select unit is active during refresh bus cycles. This means that a chip-select will go active if the refresh address is within the limits specified for the channel. In addition, $\overline{\text{RFSH}}$ is driven active to signal that a refresh bus cycle is in progress. Data on the AD7:0 bus is ignored.

A pending refresh request will attempt to abort a HOLD/HLDA bus exchange. HLDA is deasserted when a refresh request is pending and a bus HOLD is already in progress. HOLD must then be released in order for the 80C188EB to execute the refresh bus cycle.

POWER MANAGEMENT UNIT

The 80C188EB Power Management Unit (PMU) is provided to control the power consumption of the device. The PMU provides three power modes: Active, Idle, and Powerdown.

Active Mode indicates that all units on the 80C188EB are functional and the device consumes maximum power (depending on the level of peripheral operation). Idle Mode freezes the clocks of the Execution and Bus units at a logic zero state (all peripherals continue to operate normally). An unmasked interrupt, NMI, or reset will cause the 80C188EB to exit the Idle mode.

The Powerdown mode freezes all internal clocks at a logic zero level and disables the crystal oscillator. All internal registers hold their values provided V_{CC} is maintained. Current consumption is reduced to just transistor junction leakage. An NMI or processor reset will cause the 80C188EB to exit the Powerdown Mode. A timing pin is provided to establish the length of time between exiting Powerdown and resuming device operation. (Length of time depends on startup time of crystal oscillator and is application dependent.)

ONCE™ Test Mode

To facilitate testing and inspection of devices when fixed into a target system, the 80C188EB has a test mode available which forces all output and input/output pins to be placed in the high-impedance state. ONCE stands for "ON Circuit Emulation". The ONCE mode is selected by forcing the A19/$\overline{\text{ONCE}}$ pin LOW (0) during a processor reset (this pin is weakly held to a HIGH (1) level while $\overline{\text{RESIN}}$ is active).

PACKAGE INFORMATION

This section describes the pins, pinouts, and thermal characteristics for the 80C188EB in the Plastic Leaded Chip Carrier (PLCC) package and Quad Flat Pack (QFP) package. For complete package specifications and information, see the Intel Packaging Outlines and Dimensions Guide (Order Number: 231369).

Pin Descriptions

The 80C188EB pins are described in this section. Table 3 presents the legend for interpreting the pin descriptions in Table 4. Figure 7 provides an example pin description entry. The "I/O" signifies that the pins are bidirectional (i.e., have both an input and output function). The "S" indicates that, as an input, the signal is synchronized to CLKOUT for proper operation. The "H(Z)" indicates that these pins will float while the processor is in the Hold Acknowledge state. R(Z) indicates that these pins will float while $\overline{RESIN}$ is low. P(X) Indicates that these pins will retain their current value when Idle or Powerdown Modes are entered.

All pins float while the processor is in the ONCE™ Mode.

Name	Type	Description
AD7:0	I/O S(L) H(Z) R(Z) P(X)	These pins provide a multiplexed ADDRESS and DATA bus. During the address phase of the bus cycle, address bits 0 through 15 are presented on the bus and can be latched using ALE. 8-bit data information are transferred during the data phase of the bus cycle.

Figure 7. Example Pin Description Entry

Table 3. Pin Description Nomenclature

Symbol	Description
I	Input Only Pin
O	Output Only Pin
I/O	Pin can be either input or output
—	Pin "must be" connected as described
S(..)	Synchronous. Input must meet setup and hold times for proper operation of the processor. The pin is: S(E) edge sensitive S(L) level sensitive
A(..)	Asynchronous. Input must meet setup and hold only to guarantee recognition. The pin is: A(E) edge sensitive A(L) level sensitive
H(..)	While the processor's bus is in the Hold Acknowledge state, the pin: H(1) is driven to V_{CC} H(0) is driven to V_{SS} H(Z) floats H(Q) remains active H(X) retains current state
R(..)	While the processor's $\overline{RES}$ line is low, the pin: R(1) is driven to V_{CC} R(0) is driven to V_{SS} R(Z) floats R(WH) weak pullup R(WL) weak pulldown
P(..)	While Idle or Powerdown modes are active, the pin: P(1) is driven to V_{CC} P(0) is driven to V_{SS} P(Z) floats P(Q) remains active(1) P(X) retains current state

NOTE:
1. Any pin that specifies P(Q) are valid for Idle Mode. All pins are P(X) for Powerdown Mode.

Table 3. 80C188EB Pin Descriptions

Name	Type	Description
V_{CC}		**POWER** connections consist of four pins which must be shorted externally to a V_{CC} board plane.
V_{SS}		**GROUND** connections consist of six pins which must be shorted externally to a V_{SS} board plane.
CLKIN	I A(E)	**CLock INput** is an input for an external clock. An external oscillator operating at two times the required 80C188EB operating frequency can be connected to CLKIN. For crystal operation, CLKIN (along with OSCOUT) are the crystal connections to an internal Pierce oscillator.
OSCOUT	O H(Q) R(Q) P(X)	**OSCillator OUTput** is only used when using a crystal to generate the external clock. OSCOUT (along with CLKIN) are the crystal connections to an internal Pierce oscillator. This pin is not to be used as 2X clock output for non-crystal applications (i.e., this pin is N.C. for non-crystal applications).
CLKOUT	O H(Q) R(Q) P(1)	**CLock OUTput** provides a timing reference for inputs and outputs of the processor, and is one-half the input clock (CLKIN) frequency. CLKOUT has a 50% duty cycle and transistions every falling edge of CLKIN.
$\overline{\text{RESIN}}$	I A(L)	**RESet IN** causes the 80C188EB to immediately terminate any bus cycle in progress and assume an initialized state. All pins will be driven to a known state, and RESOUT will also be driven active. The rising edge (low-to-high) transition synchronizes CLKOUT with $\overline{\text{CLKIN}}$ before the 80C188EB begins fetching opcodes at memory location 0FFFF0H.
RESOUT	O H(0) R(1) P(0)	**RESet OUTput** that indicates the 80C188EB is currently in the reset state. RESOUT will remain active as long as $\overline{\text{RESIN}}$ remains active.
PDTMR	I/O A(L) H(WH) R(Z) P(WH)	**Power-Down TiMeR** pin (normally connected to an external capacitor) that determines the amount of time the 80C188EB waits after an exit from power down before resuming normal operation. The duration of time required will depend on the startup characteristics of the crystal oscillator.
NMI	I A(E)	**Non-Maskable Interrupt** input causes a TYPE-2 interrupt to be serviced by the CPU. NMI is latched internally.
$\overline{\text{TEST}}$	I A(E)	**TEST** is used during the execution of the WAIT instruction to suspend CPU operation until the pin is sampled active (LOW).
AD7:0	I/O S(L) H(Z) R(Z) P(X)	These pins provide a multiplexed ADDRESS and DATA bus. During the address phase of the bus cycle, address bits 0 through 7 are presented on the bus and can be latched using ALE. 8-bit data information is transferred during the data phase of the bus cycle.
A15:8	O H(Z) R(Z) P(X)	These pins provide address information throughout the entire bus cycle.

Table 3. 80C188EB Pin Descriptions (Continued)

Name	Type	Description
A18:16 A19/$\overline{ONCE}$	I/O H(Z) R(W1) P(Z)	These pins provide multiplexed ADDRESS during the address phase of the bus cycle. Address bits 16 through 19 are presented on these pins and can be latched using ALE. These pins are driven to a logic 0 during the data phase of the bus cycle. During a processor reset ($\overline{RESIN}$ active), A19/$\overline{ONCE}$ is used to enable ONCE mode. A18:16 must not be driven low during reset or improper 80C188EB operation may result.
$\overline{S2:0}$	O H(Z) R(1) P(1)	Bus cycle **Status** are encoded on these pins to provide bus transaction information. $\overline{S2:0}$ are encoded as follows: $\overline{S2}$ $\overline{S1}$ $\overline{S0}$ Bus Cycle Initiated 0 0 0 Interrupt Acknowledge 0 0 1 Read I/O 0 1 0 Write I/O 0 1 1 Processor HALT 1 0 0 Queue Instruction Fetch 1 0 1 Read Memory 1 1 0 Write Memory 1 1 1 Passive (no bus activity)
ALE	O H(0) R(0) P(0)	**Address Latch Enable** output is used to strobe address information into a transparent type latch during the address phase of the bus cycle.
$\overline{RFSH}$	O H(Z) R(Z) P(1)	**ReFreSH** output signals that a refresh bus cycle is in progress.
$\overline{RD}$	O H(Z) R(Z) P(1)	**ReaD** output signals that the accessed memory or I/O device must drive data information onto the data bus.
$\overline{WR}$	O H(Z) R(Z) P(1)	**WRite** output signals that data available on the data bus are to be written into the accessed memory or I/O device.
READY	I A(L) S(L)	**READY** input to signal the completion of a bus cycle. READY must be active to terminate any 80C188EB bus cycle, unless it is ignored by correctly programming the Chip-Select Unit.
$\overline{DEN}$	O H(Z) R(Z) P(1)	**Data ENable** output to control the enable of bi-directional transceivers when buffering a 80C188EB system. $\overline{DEN}$ is active only when data is to be transferred on the bus.

Table 3. 80C188EB Pin Descriptions (Continued)

Name	Type	Description
DT/$\overline{R}$	O H(Z) R(Z) P(X)	**Data Transmit/Receive** output controls the direction of a bi-directional buffer when buffering an 80C188EB system. DT/$\overline{R}$ is only available for the PLCC package (N80C188EB).
$\overline{LOCK}$	I/O H(Z) R(W1) P(1)	**LOCK** output indicates that the bus cycle in progress is not to be interrupted. The 80C188EB will not service other bus requests (such as HOLD) while $\overline{LOCK}$ is active. This pin is configured as a weakly held high input while $\overline{RESIN}$ is active and must not be driven low.
HOLD	I A(L)	**HOLD** request input to signal that an external bus master wishes to gain control of the local bus. The 80C188EB will relinquish control of the local bus between instruction boundaries not conditioned by a LOCK prefix.
HLDA	O H(1) R(0) P(0)	**HoLD Acknowledge** output to indicate that the 80C188EB has relinquish control of the local bus. When HLDA is asserted, the 80C188EB will (or has) floated its' data bus and control signals allowing another bus master to drive the signals directly.
$\overline{UCS}$	O H(1) R(1) P(1)	**Upper Chip Select** will go active whenever the address of a memory or I/O bus cycle is within the address limitations programmed by the user. After reset, $\overline{UCS}$ is configured to be active for memory accesses between 0FFC00H and 0FFFFFH.
$\overline{LCS}$	O H(1) R(1) P(1)	**Lower Chip Select** will go active whenever the address of a memory bus cycle is within the address limitations programmed by the user. $\overline{LCS}$ is inactive after a reset.
P1.0/$\overline{GCS0}$ P1.1/$\overline{GCS1}$ P1.2/$\overline{GCS2}$ P1.3/$\overline{GCS3}$ P1.4/$\overline{GCS4}$ P1.5/$\overline{GCS5}$ P1.6/$\overline{GCS6}$ P1.7/$\overline{GCS7}$	O H(X)/H(1) R(1) P(X)/P(1)	These pins provide a multiplexed function. If enabled, each pin can provide a **Generic Chip Select** output which will go active whenever the address of a memory or I/O bus cycle is within the address limitations programmed by the user. When not programmed as a Chip-Select, each pin may be used as a general purpose output **Port.** As an output port pin, the value of the pin can be read internally.
T0OUT T1OUT	O H(Q) R(1) P(Q)	**Timer OUTput** pins can be programmed to provide a single clock or continuous waveform generation, depending on the timer mode selected.
T0IN T1IN	I A(L) A(E)	**Timer INput** is used either as clock or control signals, depending on the timer mode selected.

Table 3. 80C188EB Pin Descriptions (Continued)

Name	Type	Description
INT0 INT1 INT4	I A(E,L)	Maskable **INTerrupt** input will cause a vector to a specific Type interrupt routine. To allow interrupt expansion, INT0 and/or INT1 can be used with $\overline{\text{INTA0}}$ and $\overline{\text{INTA1}}$ to interface with an external slave controller.
INT2/$\overline{\text{INTA0}}$ INT3/$\overline{\text{INTA1}}$	I/O A(E,L) /H(1) R(Z) /P(1)	These pins provide a multiplexed function. As inputs, they provide a maskable **INTerrupt** that will cause the CPU to vector to a specific Type interrupt routine. As outputs, each is programmatically controlled to provide an INTERRUPT ACKNOWLEDGE handshake signal to allow interrupt expansion.
P2.7 P2.6	I/O A(L) H(X) R(Z) P(X)	BI-DIRECTIONAL, open-drain **Port** pins.
$\overline{\text{CTS0}}$ P2.4/$\overline{\text{CTS1}}$	I A(L)	**Clear-To-Send** input is used to prevent the transmission of serial data on the TXD signal pin. $\overline{\text{CTS1}}$ is multiplexed with an input only port function.
TXD0 P2.1/TXD1	O H(X)/H(Q) R(1) P(X)/P(Q)	**Transmit Data** output provides serial data information. TXD1 is multiplexed with an output only **Port** function. During synchronous serial communications, TXD will function as a clock output.
RXD0 P2.0/RXD1	I/O A(L) R(Z) H(Q) P(X)	**Receive Data** input accepts serial data information. RXD1 is multiplexed with an input only **Port** function. During synchronous serial communications, RXD is bi-directional and will become an output for transmission or data (TXD becomes the clock).
P2.5/BCLK0 P2.2/BCLK1	I A(L)/A(E)	**Baud CLocK** input can be used as an alternate clock source for each of the integrated serial channels. BCLKx is multiplexed with an input only **Port** function, and cannot exceed a clock rate greater than one-half the operating frequency of the 80C188EB.
P2.3/SINT1	O H(X)/H(Q) R(0) P(X)/P(Q)	**Serial INTerrupt** output will go active to indicate serial channel 1 requires service. SINT1 is multiplexed with an output only **Port** function.

80C188EB PINOUT

Tables 4 and 5 list the 80C188EB pin names with package location for the 84-pin Plastic Leaded Chip Carrier (PLCC) component. Figure 7 depicts the complete 80C188EB pinout (PLCC package) as viewed from the top side of the component (i.e., contacts facing down).

Tables 6 and 7 list the 80C188EB pin names with package location for the 80-pin Quad Flat Pack (QFP) component. Figure 8 depicts the complete 80C188EB (QFP package) as viewed from the top side of the component (i.e., contacts facing down).

Table 4. PLCC Pin Names with Package Location

Address/Data Bus		Bus Control		Processor Control		I/O	
Name	**Location**	**Name**	**Location**	**Name**	**Location**	**Name**	**Location**
AD0	61	ALE	6	$\overline{RESIN}$	37	$\overline{UCS}$	30
AD1	66	$\overline{RFSH}$	7	RESOUT	38	$\overline{LCS}$	29
AD2	68	$\overline{S0}$	10	CLKIN	41	P1.0/$\overline{GCS0}$	28
AD3	70	$\overline{S1}$	9	OSCOUT	40	P1.1/$\overline{GCS1}$	27
AD4	72	$\overline{S2}$	8	CLKOUT	44	P1.2/$\overline{GCS2}$	26
AD5	74	$\overline{RD}$	4	$\overline{TEST}$	14	P1.3/$\overline{GCS3}$	25
AD6	76	$\overline{WR}$	5	NC	60	P1.4/$\overline{GCS4}$	24
AD7	78	READY	18	NC	39	P1.5/$\overline{GCS5}$	21
A8	62	$\overline{DEN}$	11	NC	3	P1.6/$\overline{GCS6}$	20
A9	67	DT/$\overline{R}$	16	PDTMR	36	P1.7/$\overline{GCS7}$	19
A10	69	$\overline{LOCK}$	15	NMI	17	T0OUT	45
A11	71	HOLD	13	INT0	31	T0IN	46
A12	73	HLDA	12	INT1	32	T1OUT	47
A13	75	V_{SS}	2, 22, 43	INT2/$\overline{INTA0}$	33	T1IN	48
A14	77	V_{SS}	63, 65, 84	INT3/$\overline{INTA1}$	34	RXD0	53
A15	79			INT4	35	TXD0	52
A16	80			V_{CC}	1, 23,	P2.5/BCLK0	54
A17	81			V_{CC}	42, 64	$\overline{CTS0}$	51
A18	82					P2.0/RXD1	57
A19/$\overline{ONCE}$	83					P2.1/TXD1	58
						P2.2/BCLK1	59
						P2.3/SINT1	55
						P2.4/$\overline{CTS1}$	56
						P2.6	50
						P2.7	49

Table 5. PLCC Package Locations with Pin Name

Location	Name	Location	Name	Location	Name	Location	Name
1	V_{CC}	22	V_{SS}	43	V_{SS}	64	V_{CC}
2	V_{SS}	23	V_{CC}	44	CLKOUT	65	V_{SS}
3	NC	24	P1.4/$\overline{GCS4}$	45	T0OUT	66	AD1
4	$\overline{RD}$	25	P1.3/$\overline{GCS3}$	46	T0IN	67	A9
5	$\overline{WR}$	26	P1.2/$\overline{GCS2}$	47	T1OUT	68	AD2
6	ALE	27	P1.1/$\overline{GCS1}$	48	T1IN	69	A10
7	$\overline{RFSH}$	28	P1.0/$\overline{GCS0}$	49	P2.7	70	AD3
8	$\overline{S2}$	29	$\overline{LCS}$	50	P2.6	71	A11
9	$\overline{S1}$	30	$\overline{UCS}$	51	$\overline{CTS0}$	72	AD4
10	$\overline{S0}$	31	INT0	52	TXD0	73	A12
11	$\overline{DEN}$	32	INT1	53	RXD0	74	AD5
12	HLDA	33	INT2/$\overline{INTA0}$	54	P2.5/BCLK0	75	A13
13	HOLD	34	INT3/$\overline{INTA1}$	55	P2.3/SINT1	76	AD6
14	$\overline{TEST}$	35	INT4	56	P2.4/$\overline{CTS1}$	77	A14
15	$\overline{LOCK}$	36	PDTMR	57	P2.0/RXD1	78	AD7
16	DT/$\overline{R}$	37	$\overline{RESIN}$	58	P2.1/TXD1	79	A15
17	NMI	38	RESOUT	59	P2.2/BCLK1	80	A16
18	READY	39	NC	60	NC	81	A17
19	P1.7/$\overline{GCS7}$	40	OSCOUT	61	AD0	82	A18
20	P1.6/$\overline{GCS6}$	41	CLKIN	62	A8	83	A19/$\overline{ONCE}$
21	P1.5/$\overline{GCS5}$	42	V_{CC}	63	V_{SS}	84	V_{SS}

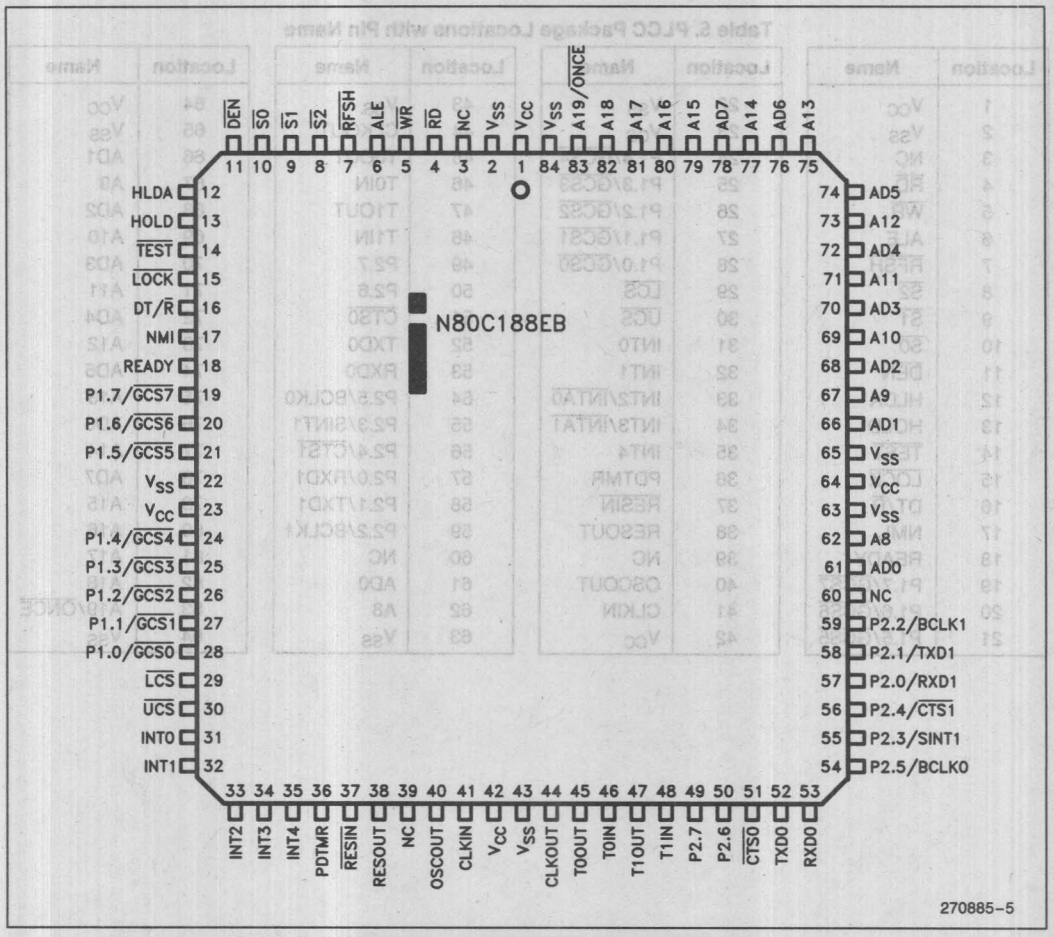


Figure 7. 84-Pin Plastic Leaded Chip Carrier Pinout Diagram

Table 6. QFP Pin Name with Package Location

Address/Data Bus	
Name	**Location**
AD0	10
AD1	15
AD2	17
AD3	19
AD4	21
AD5	23
AD6	25
AD7	27
A8	11
A9	16
A10	18
A11	20
A12	22
A13	24
A14	26
A15	28
A16	29
A17	30
A18	31
A19/$\overline{\text{ONCE}}$	32

Bus Control	
Name	**Location**
ALE	38
$\overline{\text{RFSH}}$	39
$\overline{\text{S0}}$	42
$\overline{\text{S1}}$	41
$\overline{\text{S2}}$	40
$\overline{\text{RD}}$	36
$\overline{\text{WR}}$	37
READY	49
$\overline{\text{DEN}}$	43
$\overline{\text{LOCK}}$	47
HOLD	45
HLDA	44

Processor Control	
Name	**Location**
$\overline{\text{RESIN}}$	68
RESOUT	69
CLKIN	71
OSCOUT	70
CLKOUT	74
$\overline{\text{TEST}}$	46
PDTMR	67
NMI	48
INT0	62
INT1	63
INT2/$\overline{\text{INTA0}}$	64
INT3/$\overline{\text{INTA1}}$	65
INT4	66
V_{CC}	13, 34
V_{CC}	54, 72
V_{SS}	12, 14, 33
V_{SS}	35, 53, 73

I/O	
Name	**Location**
$\overline{\text{UCS}}$	61
$\overline{\text{LCS}}$	60
P1.0/$\overline{\text{GCS0}}$	59
P1.1/$\overline{\text{GCS1}}$	58
P1.2/$\overline{\text{GCS2}}$	57
P1.3/$\overline{\text{GCS3}}$	56
P1.4/$\overline{\text{GCS4}}$	55
P1.5/$\overline{\text{GCS5}}$	52
P1.6/$\overline{\text{GCS6}}$	51
P1.7/$\overline{\text{GCS7}}$	50
T0OUT	75
T0IN	76
T1OUT	77
T1IN	78
RXD0	3
TXD0	2
P2.5/BCLK0	4
$\overline{\text{CTS0}}$	1
P2.0/RXD1	7
P2.1/TXD1	8
P2.2/BCLK1	9
P2.3/SINT1	5
P2.4/$\overline{\text{CTS1}}$	6
P2.6	80
P2.7	79

Table 7. QFP Package Location with Pin Names

Location	Name
1	$\overline{CTS0}$
2	TXD0
3	RXD0
4	P2.5/BCLK0
5	P2.3/SINT1
6	P2.4/$\overline{CTS1}$
7	P2.0/RXD1
8	P2.1/TXD1
9	P2.2/BCLK1
10	AD0
11	A8
12	V_{SS}
13	V_{CC}
14	V_{SS}
15	AD1
16	A9
17	AD2
18	A10
19	AD3
20	A11
21	AD4
22	A12
23	AD5
24	A13
25	AD6
26	A14
27	AD7
28	A15
29	A16
30	A17
31	A18
32	A19/$\overline{ONCE}$
33	V_{SS}
34	V_{CC}
35	V_{SS}
36	$\overline{RD}$
37	$\overline{WR}$
38	ALE
39	$\overline{RFSH}$
40	$\overline{S2}$
41	$\overline{S1}$
42	$\overline{S0}$
43	$\overline{DEN}$
44	HLDA
45	HOLD
46	$\overline{TEST}$
47	$\overline{LOCK}$
48	NMI
49	READY
50	P1.7/$\overline{GCS7}$
51	P1.6/$\overline{GCS6}$
52	P1.5/$\overline{GCS5}$
53	V_{SS}
54	V_{CC}
55	P1.4/$\overline{GCS4}$
56	P1.3/$\overline{GCS3}$
57	P1.2/$\overline{GCS2}$
58	P1.1/$\overline{GCS1}$
59	P1.0/$\overline{GCS0}$
60	$\overline{LCS}$
61	$\overline{UCS}$
62	INT0
63	INT1
64	INT2/$\overline{INTA0}$
65	INT3/$\overline{INTA1}$
66	INT4
67	PDTMR
68	$\overline{RESIN}$
69	RESOUT
70	OSCOUT
71	CLKIN
72	V_{CC}
73	V_{SS}
74	CLKOUT
75	T0OUT
76	T0IN
77	T1OUT
78	T1IN
79	P2.7
80	P2.6

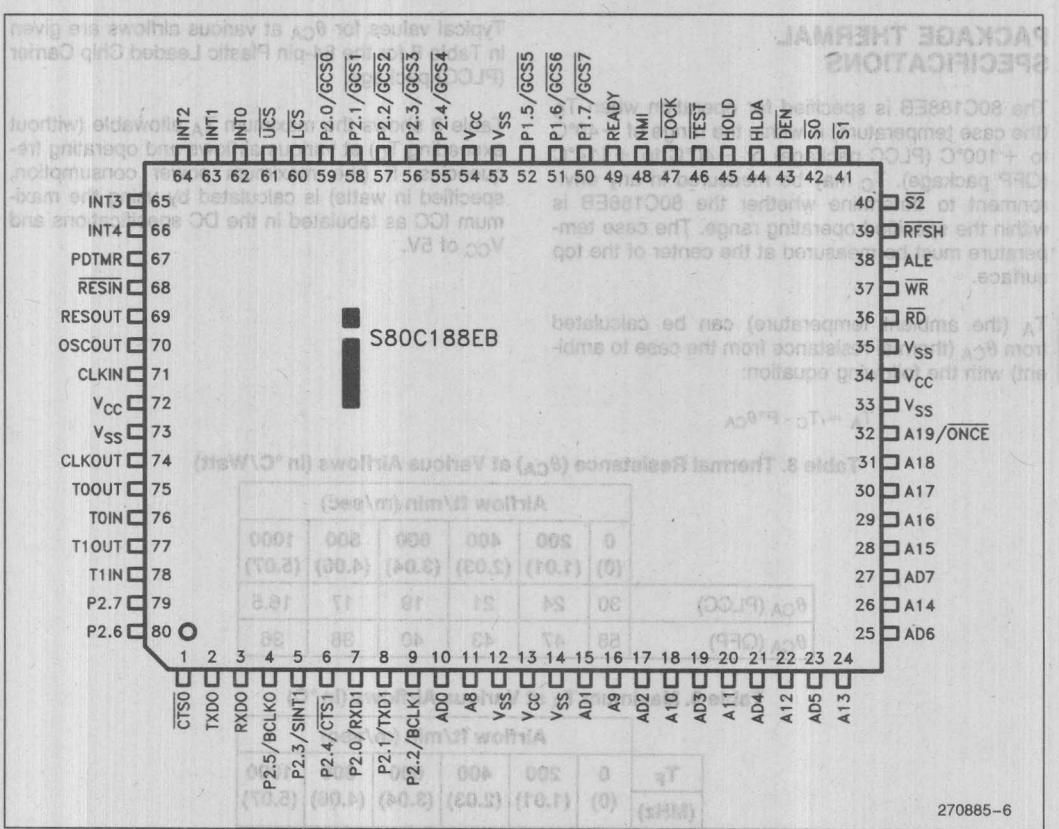


Figure 8. Quad Flat Pack Pinout Diagram

PACKAGE THERMAL SPECIFICATIONS

The 80C188EB is specified for operation when T_C (the case temperature) is within the range of −40°C to +100°C (PLCC package) or −40°C to +114°C (QFP package). T_C may be measured in any environment to determine whether the 80C188EB is within the specified operating range. The case temperature must be measured at the center of the top surface.

T_A (the ambient temperature) can be calculated from θ_{CA} (thermal resistance from the case to ambient) with the following equation:

$$T_A = T_C - P*\theta_{CA}$$

Typical values for θ_{CA} at various airflows are given in Table 8 for the 84-pin Plastic Leaded Chip Carrier (PLCC) package.

Table 9 shows the maximum T_A allowable (without exceeding T_C) at various airflows and operating frequencies. P (the maximum power consumption, specified in watts) is calculated by using the maximum ICC as tabulated in the DC specifications and V_{CC} of 5V.

Table 8. Thermal Resistance (θ_{CA}) at Various Airflows (in °C/Watt)

	Airflow ft/min (m/sec)					
	0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
θ_{CA} (PLCC)	30	24	21	19	17	16.5
θ_{CA} (QFP)	58	47	43	40	38	36

Table 9. Maximum T_A at Various Airflows (in °C)

		Airflow ft/min (m/sec)					
	T_F (MHz)	0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
T_A (PLCC)	16	91.5	93.5	94	94.5	95.5	95.5
	26	88.5	91	92	92.5	93.5	93.5
	32	85	87.5	89.5	90.5	91.5	92
T_A (QFP)	16	98	101	102	103	103.5	104
	26	92	96	97.5	99	99.5	100
	32	85	90.5	92.5	94	95	96

ELECTRICAL SPECIFICATIONS

NOTICE: This document contains information on products in the design phase of development. Do not finalize a design with this information. Revised information will be published when the product is available.

Absolute Maximum Ratings

Parameter	Maximum Rating
Storage Temperature	−65°C to +150°C
Case Temp Under Bias	−65°C to +120°C
Supply Voltage wrt V_{SS}	−0.5V to +6.5V
Voltage on other Pins wrt. V_{SS}	−0.5V to V_{CC} +0.5V

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

1

The data present in this document are provided as a PREVIEW of expected device performance. Since Intel currently does not produce a product that complies with these specifications, this data sheet should not be used as the basis for a final design. Once information corresponding to an actual device is available, an ADVANCED INFORMATION data sheet will be published to supercede this document.

OPERATING CONDITIONS

Symbol	Parameter	Min	Max	Units
V_{CC}	Supply Voltage	4.5	5.5	V
T_F	Input Clock Frequency			
	80C188EB-16	0	32	MHz
	80C188EB-13	0	26.08	MHz
	80C188EB	0	16	MHz
T_C	Case Temperature Under Bias			
	N80C188EB-XX (PLCC)	−40	+100	°C
	S80C188EB-XX (QFP)	−40	+114	°C

RECOMMENDED CONNECTIONS

Power and ground connections must be made to multiple V_{CC} and V_{SS} pins. Every 80C188EB-based circuit board should include separate power (V_{CC}) and ground (V_{SS}) planes. Every V_{CC} pin must be connected to the power plane, and every V_{SS} pin must be connected to the ground plane. Pins identified as "NC" must not be connected in the system. Liberal decoupling capacitance should be placed near the 80C188EB. The processor can cause transient power surges when its output buffers transition, particularly when connected to large capacitive loads.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance is reduced by placing the decoupling capacitors as close as possible to the 80C188EB V_{CC} and V_{SS} package pins.

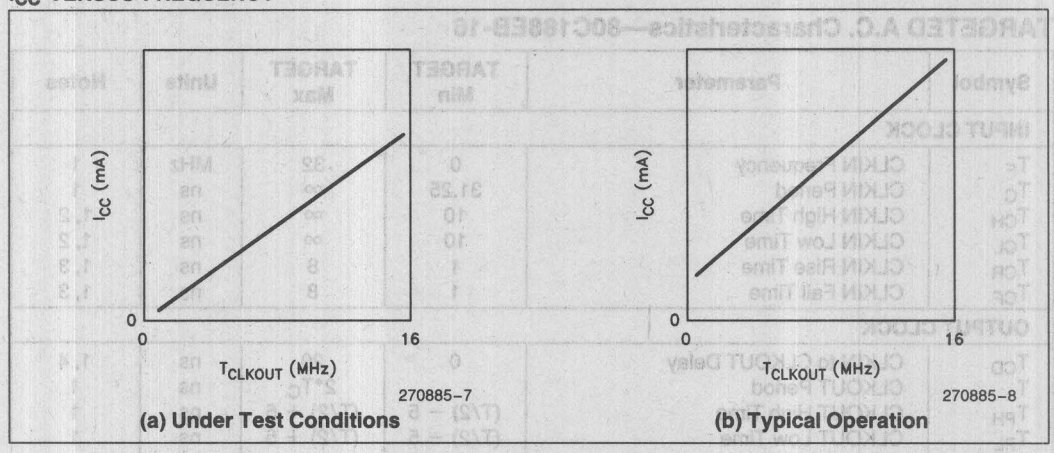
Always connect any unused input to an appropriate signal level. In particular, unused interrupt inputs (NMI, INT0:4) should be connected to V_{CC} through a pull-up resistor (in the range of 50 KΩ). **Leave any unused output pin or any NC pin unconnected.**

TARGETED D.C. SPECIFICATIONS

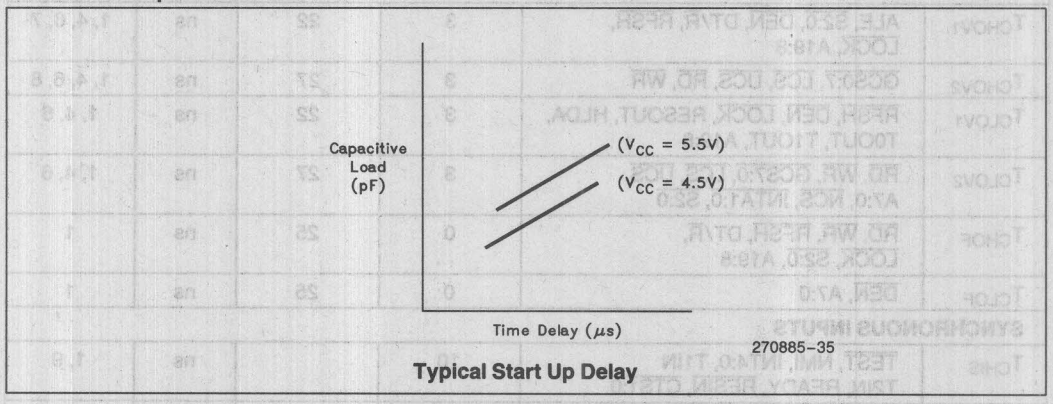
Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage	−0.5	0.3*V_{CC}	V	
V_{IH}	Input High Voltage	0.7*V_{CC}	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 3 mA (Min)
V_{OH}	Output High Voltage	V_{CC} − 0.5		V	I_{OH} = −2 mA (Mln)
V_{HYR}	Input Hysterisis on $\overline{RESIN}$	0.65		V	
I_{IL1}	Input Leakage Current for pins: AD7:0, READY, HOLD, $\overline{RESIN}$, CLKIN, $\overline{TEST}$, NMI, INT4:0, T0IN, T1IN, RXD0, $\overline{BCLK0}$, $\overline{CTS0}$, RXD1, $\overline{BCLK1}$, $\overline{CTS1}$, SINT1, P2.6, P2.7		±15	μA	0V ≤ V_{IN} ≤ V_{CC}
I_{IL3}	Input Leakage Current for pins: A19/$\overline{ONCE}$, A18:16, $\overline{LOCK}$		−2	mA	V_{IN} = 0.7 V_{CC} (Note 1)
I_{OL}	Output Leakage Current		±15	μA	0.45 ≤ V_{OUT} ≤ V_{CC} (Note 2)
I_{CC}	Supply Current Cold (RESET)				
	80C188EB-16		90	mA	(Note 3)
	80C188EB-13		70	mA	(Note 3)
	80C188EB-8		50	mA	(Note 3)
I_{ID}	Supply Current Idle				
	80C188EB-16		63	mA	
	80C188EB-13		42	mA	
	80C188EB-8		35	mA	
I_{PD}	Supply Current Powerdown				
	80C188EB-16		100	μA	
	80C188EB-13		100	μA	
	80C188EB-8		100	μA	
CIN	Input Pin Capacitance	0	15	pF	T_F = 1 MHz
COUT	Output Pin Capacitance	0	15	pF	T_F = 1 MHz (Note 4)

NOTES:
1. These pins have an internal pull-up resistor that is active while $\overline{RESIN}$ is low and ONCE Mode is not active.
2. Output pins being floated during HOLD or by invoking the ONCE Mode.
3. Measured at worst case frequency, V_{CC}, and temperature with all outputs loaded as specified in A.C. Test Conditions, and the $\overline{RESIN}$ pin held low.
4. Output capacitance is the capacitive load of a floating output pin.

I_{CC} VERSUS FREQUENCY



PDTMR Pin Capacitance Chart



Typical Start Up Delay

TARGETED A.C. SPECIFICATIONS

TARGETED A.C. Characteristics—80C188EB-16

Symbol	Parameter	TARGET Min	TARGET Max	Units	Notes
INPUT CLOCK					
T_F	CLKIN Frequency	0	32	MHz	1
T_C	CLKIN Period	31.25	∞	ns	1
T_{CH}	CLKIN High Time	10	∞	ns	1, 2
T_{CL}	CLKIN Low Time	10	∞	ns	1, 2
T_{CR}	CLKIN Rise Time	1	8	ns	1, 3
T_{CF}	CLKIN Fall Time	1	8	ns	1, 3
OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	20	ns	1, 4
T	CLKOUT Period		2*T_C	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{RFSH}$, $\overline{LOCK}$, A19:8	3	22	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{RD}$, $\overline{WR}$	3	27	ns	1, 4, 6, 8
T_{CLOV1}	$\overline{RFSH}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:8	3	22	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, A7:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	27	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{RFSH}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:8	0	25	ns	1
T_{CLOF}	$\overline{DEN}$, A7:0	0	25	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	A7:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, A7:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$	10		ns	1, 9
T_{CLIH}	HOLD	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{RFSH}$, $\overline{LOCK}$ and A19:8 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C188EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED A.C. Characteristics—80C188EB-13

Symbol	Parameter	TARGET Min	TARGET Max	Units	Notes
INPUT CLOCK					
T_F	CLKIN Frequency	0	26.08	MHz	1
T_C	CLKIN Period	38.34	∞	ns	1
T_{CH}	CLKIN High Time	12	∞	ns	1, 2
T_{CL}	CLKIN Low Time	12	∞	ns	1, 2
T_{CR}	CLKIN Rise Time	1	8	ns	1, 3
T_{CF}	CLKIN Fall Time	1	8	ns	1, 3
OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	23	ns	1, 4
T	CLKOUT Period		$2*T_C$	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{RFSH}$, $\overline{LOCK}$, A19:8	3	25	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{RD}$, $\overline{WR}$	3	30	ns	1, 4, 6, 8
T_{CLOV1}	$\overline{RFSH}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:8	3	25	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, A7:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	30	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{RFSH}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:8	0	25	ns	1
T_{CLOF}	$\overline{DEN}$, A7:0	0	25	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	A7:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, A7:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$	10		ns	1, 9
T_{CLIH}	HOLD	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{RFSH}$, $\overline{LOCK}$ and A8:0 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C188EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED A.C. Characteristics—80C188EB-8

Symbol	Parameter	TARGET Min	TARGET Max	Units	Notes
INPUT CLOCK					
T_F	CLKIN Frequency	0	16	MHz	1
T_C	CLKIN Period	62.5	∞	ns	1
T_{CH}	CLKIN High Time	15	∞	ns	1, 2
T_{CL}	CLKIN Low Time	15	∞	ns	1, 2
T_{CR}	CLKIN Rise Time	1	8	ns	1, 3
T_{CF}	CLKIN Fall Time	1	8	ns	1, 3
OUTPUT CLOCK					
T_{CD}	CLKIN to CLKOUT Delay	0	27	ns	1, 4
T	CLKOUT Period		$2*T_C$	ns	1
T_{PH}	CLKOUT High Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PL}	CLKOUT Low Time	(T/2) − 5	(T/2) + 5	ns	1
T_{PR}	CLKOUT Rise Time	1	6	ns	1, 5
T_{PF}	CLKOUT Fall Time	1	6	ns	1, 5
OUTPUT DELAYS					
T_{CHOV1}	ALE, $\overline{S2:0}$, $\overline{DEN}$, DT/$\overline{R}$, $\overline{RFSH}$, $\overline{LOCK}$, A19:8	3	30	ns	1, 4, 6, 7
T_{CHOV2}	$\overline{GCS0:7}$, $\overline{LCS}$, $\overline{UCS}$, $\overline{RD}$, $\overline{WR}$	3	35	ns	1, 4, 6, 8
T_{CLOV1}	$\overline{RFSH}$, $\overline{DEN}$, $\overline{LOCK}$, RESOUT, HLDA, T0OUT, T1OUT, A19:8	3	30	ns	1, 4, 6
T_{CLOV2}	$\overline{RD}$, $\overline{WR}$, $\overline{GCS7:0}$, $\overline{LCS}$, $\overline{UCS}$, A7:0, $\overline{NCS}$, $\overline{INTA1:0}$, $\overline{S2:0}$	3	35	ns	1, 4, 6
T_{CHOF}	$\overline{RD}$, $\overline{WR}$, $\overline{RFSH}$, DT/$\overline{R}$, $\overline{LOCK}$, $\overline{S2:0}$, A19:8	0	30	ns	1
T_{CLOF}	$\overline{DEN}$, A7:0	0	35	ns	1
SYNCHRONOUS INPUTS					
T_{CHIS}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{RESIN}$, $\overline{CTS1:0}$	10		ns	1, 9
T_{CHIH}	$\overline{TEST}$, NMI, INT4:0, T1IN T2IN, READY, $\overline{CTS1:0}$	0		ns	1, 9
T_{CLIS}	AD7:0	10		ns	1, 10
T_{CLIS}	READY	13		ns	1, 10
T_{CLIH}	READY, A7:0	0		ns	1, 10
T_{CLIS}	HOLD, $\overline{RESIN}$	10		ns	1, 9
T_{CLIH}	HOLD	0		ns	1, 9

NOTES:
1. See **A.C. Timing Waveforms**, for waveforms and definition.
2. Measure at V_{IH} for high time, V_{IL} for low time.
3. Only required to guarantee I_{CC}. Maximum limits are bounded by T_C, T_{CH} and T_{CL}.
4. Specified for a 50 pF load, see Figure 15 for capacitive derating information.
5. Specified for a 50 pF load, see Figure 16 for rise and fall times outside 50 pF.
6. See Figure 16 for rise and fall times.
7. T_{CHOV1} applies to $\overline{RFSH}$, $\overline{LOCK}$ and A19:8 only after a HOLD release.
8. T_{CHOV2} applies to $\overline{RD}$ and $\overline{WR}$ only after a HOLD release.
9. Setup and Hold are required to guarantee recognition.
10. Setup and Hold are required for proper 80C188EB operation.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED Relative Timings (80C188EB-16, -13, -8)

Symbol	Parameter	TARGET Min	TARGET Max	Unit	Notes
RELATIVE TIMINGS					
T_{LHLL}	ALE Rising to ALE Falling	T − 15		ns	
T_{AVLL}	Address Valid to ALE Falling	½T − 10		ns	
T_{PLLL}	Chip Selects Valid to ALE Falling	½T − 10		ns	1
T_{LLAX}	Address Hold from ALE Falling	½T − 10		ns	
T_{LLWL}	ALE Falling to $\overline{WR}$ Falling	½T − 15		ns	1
T_{LLRL}	ALE Falling to $\overline{RD}$ Falling	½T − 15		ns	1
T_{WHLH}	$\overline{WR}$ Rising to ALE Rising	½T − 10		ns	1
T_{AFRL}	Address Float to $\overline{RD}$ Falling	0		ns	
T_{RLRH}	$\overline{RD}$ Falling to $\overline{RD}$ Rising	(2*T) − 5		ns	2
T_{WLWH}	$\overline{WR}$ Falling to $\overline{WR}$ Rising	(2*T) − 5		ns	2
T_{RHAX}	$\overline{RD}$ Rising to Address Active	T − 15		ns	
T_{WHDX}	Output Data Hold after $\overline{WR}$ Rising	T − 15		ns	
T_{WHPH}	$\overline{WR}$ Rising to Chip Select Rising	½T − 10		ns	1
T_{RHPH}	$\overline{RD}$ Rising to Chip Select Rising	½T − 10		ns	1
T_{PHPL}	$\overline{CS}$ Active to $\overline{CS}$ Inactive	½T − 10		ns	1
T_{OVRH}	$\overline{ONCE}$ Active to $\overline{RESIN}$ Rising	½T		ns	
T_{RHOX}	$\overline{ONCE}$ Hold from $\overline{RESIN}$ Rising	½T		ns	

NOTES:
1. Assumes equal loading on both pins.
2. Can be extended using wait states.

TARGETED A.C. SPECIFICATIONS (Continued)

TARGETED Serial Port Mode 0 Timings (80C188EB-16, -13, -8)

Symbol	Parameter	TARGET Min	TARGET Max	Unit	Notes
T_{XLXL}	TXD Clock Period	T + nT − 10		ns	1, 2
T_{XLXH}	TXD Clock Low to Clock High (n > 1)	2T − 10		ns	1, 2
T_{XLXH}	TXD Clock Low to Clock High (n > 1)	T − 10		ns	1, 2
T_{XHXL}	TXD Clock High to Clock Low	(n − 1) T − 10		ns	2
T_{QVXH}	RXD Output Data Setup to TXD Clock High	nT − 20		ns	1
T_{XHQX}	RXD Output Data Hold after TXD Clock High	T − 20		ns	1
T_{XHQZ}	RXD Output Data Float after Last TXD Clock High		T + 20	ns	1
T_{DVXH}	RXD Input Data Setup to TXD Clock High	T + 20		ns	1
T_{XHDX}	RXD Input Data Hold after TXD Clock High	0		ns	1

NOTES:
1. See Figure 14 for waveforms.
2. n is the value of the BxCMP register ignoring the iCLK bit (i.e., ICLK = 0).

A.C. TEST CONDITIONS

The A.C. specifications are tested with the 50 pF load shown in Figure 9. See the Derating Curves section to see how timings vary with load capacitance.

Specifications are measured at the $V_{CC}/2$ crossing point, unless otherwise specified. See A.C. Timing Waveforms, for A.C. specification definitions, test pins, and illustrations.

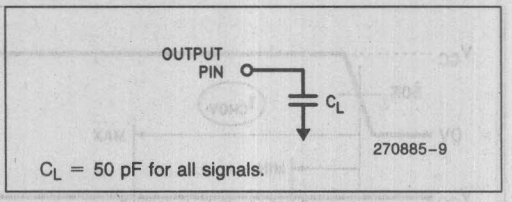


Figure 9. A.C. Test Load

A.C. TIMING WAVEFORMS

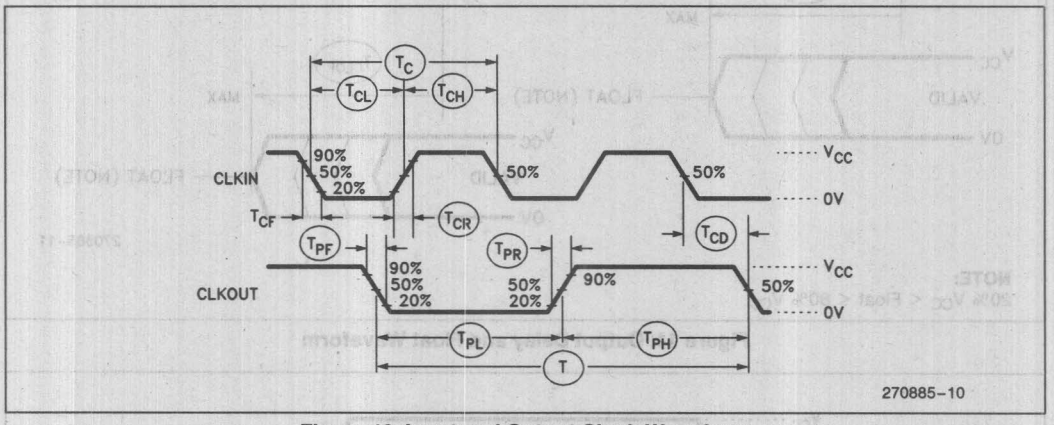


Figure 10. Input and Output Clock Waveform

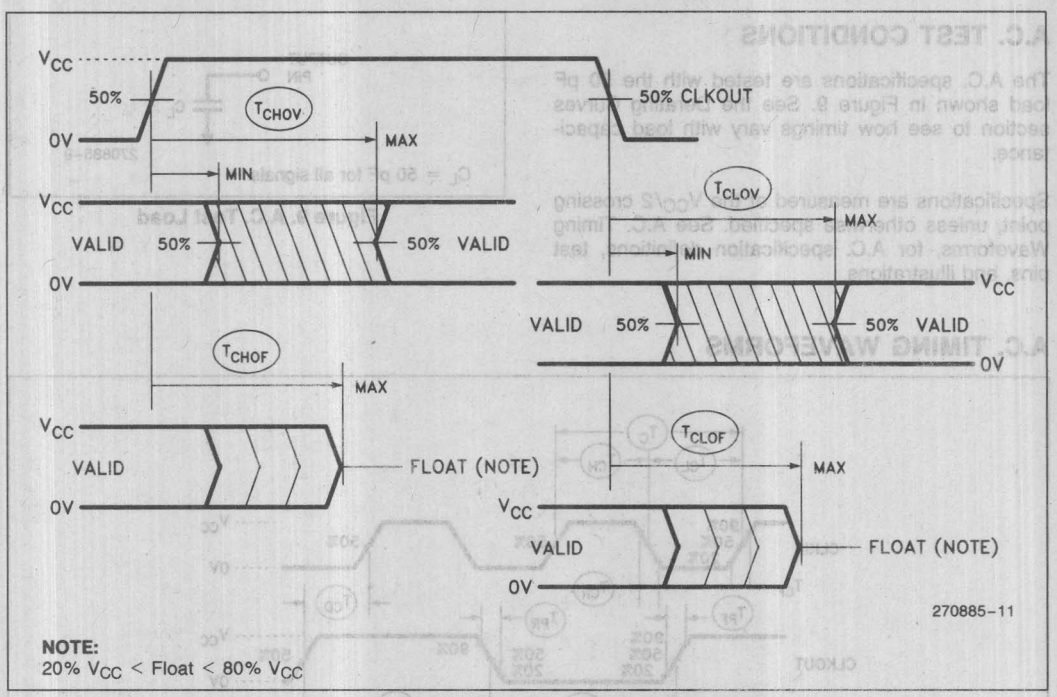


Figure 11. Output Delay and Float Waveform

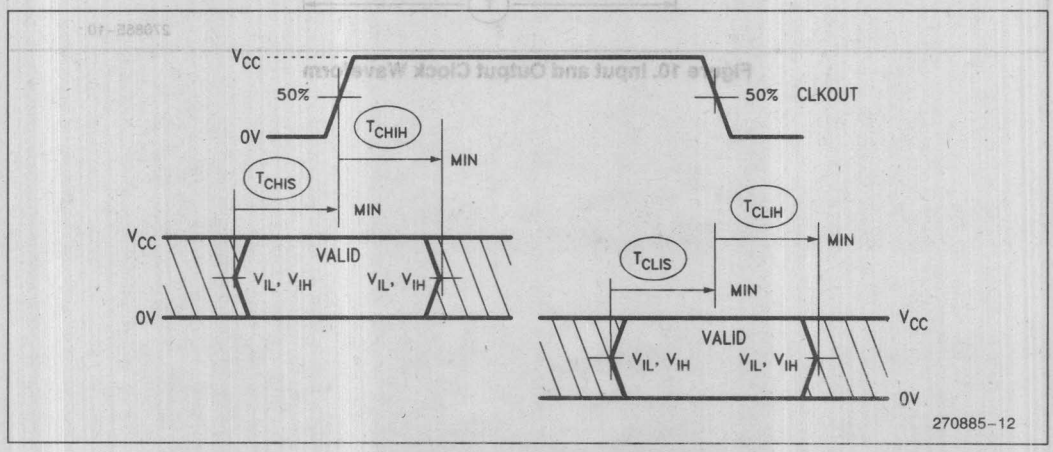


Figure 12. Input Setup and Hold

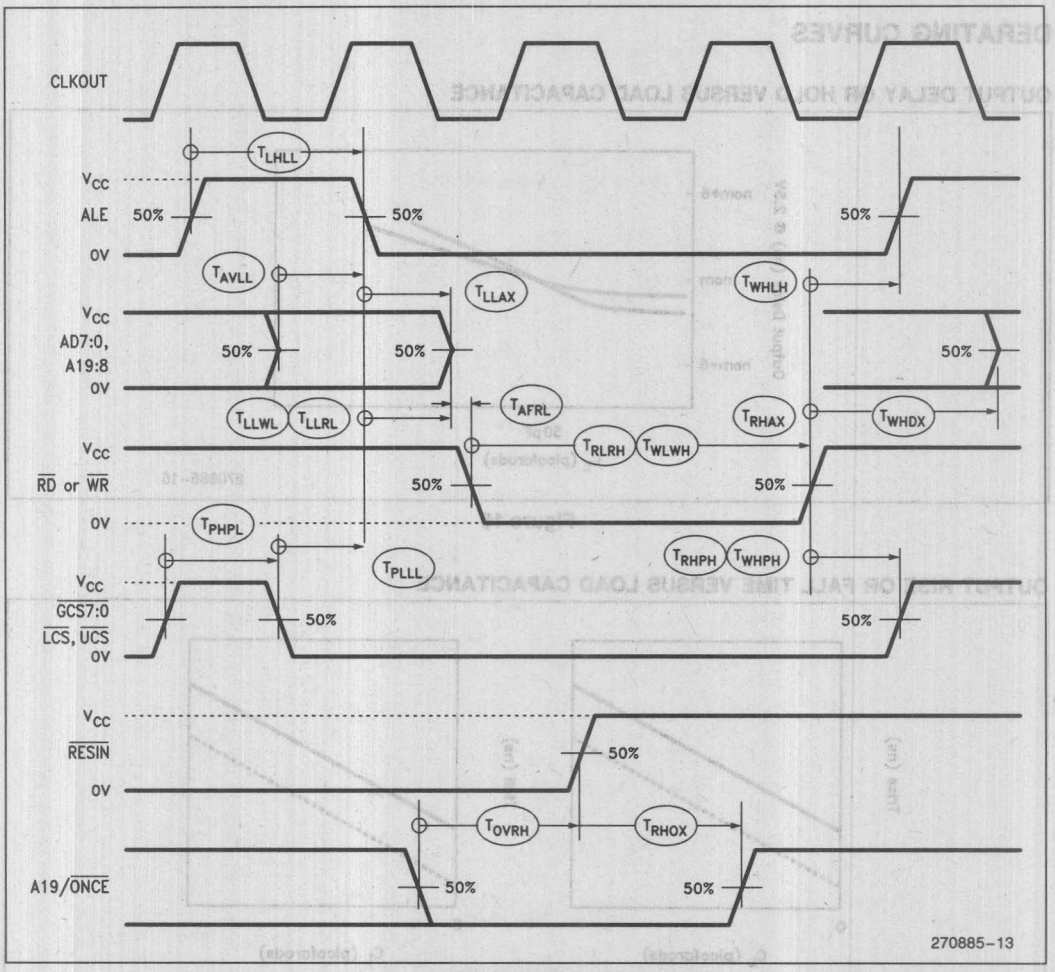


Figure 13. Relative Signal Waveform

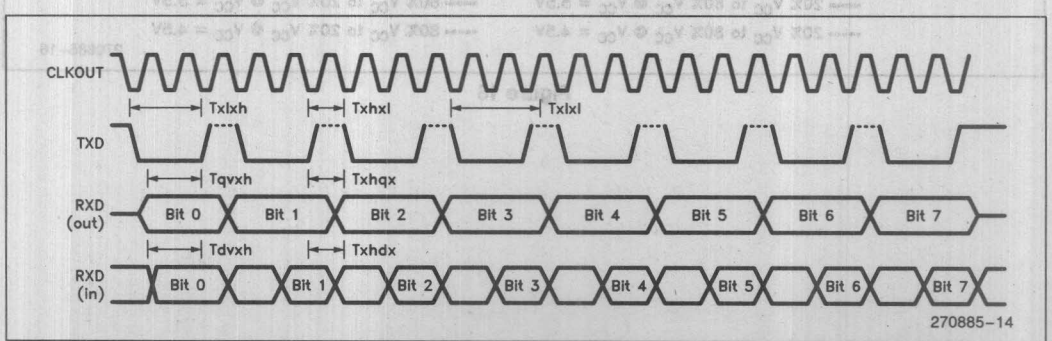


Figure 14. Serial Port Mode 0 Waveform

DERATING CURVES

OUTPUT DELAY OR HOLD VERSUS LOAD CAPACITANCE

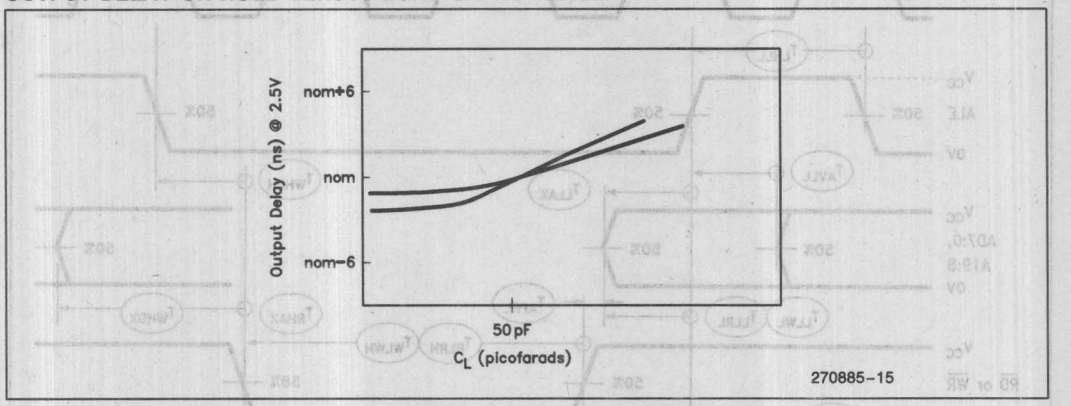


Figure 15

OUTPUT RISE OR FALL TIME VERSUS LOAD CAPACITANCE

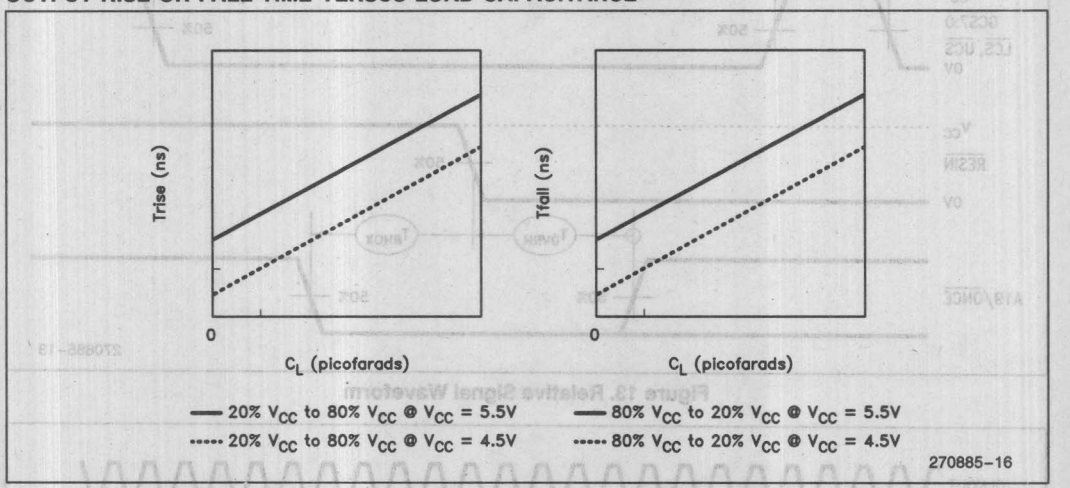


Figure 16

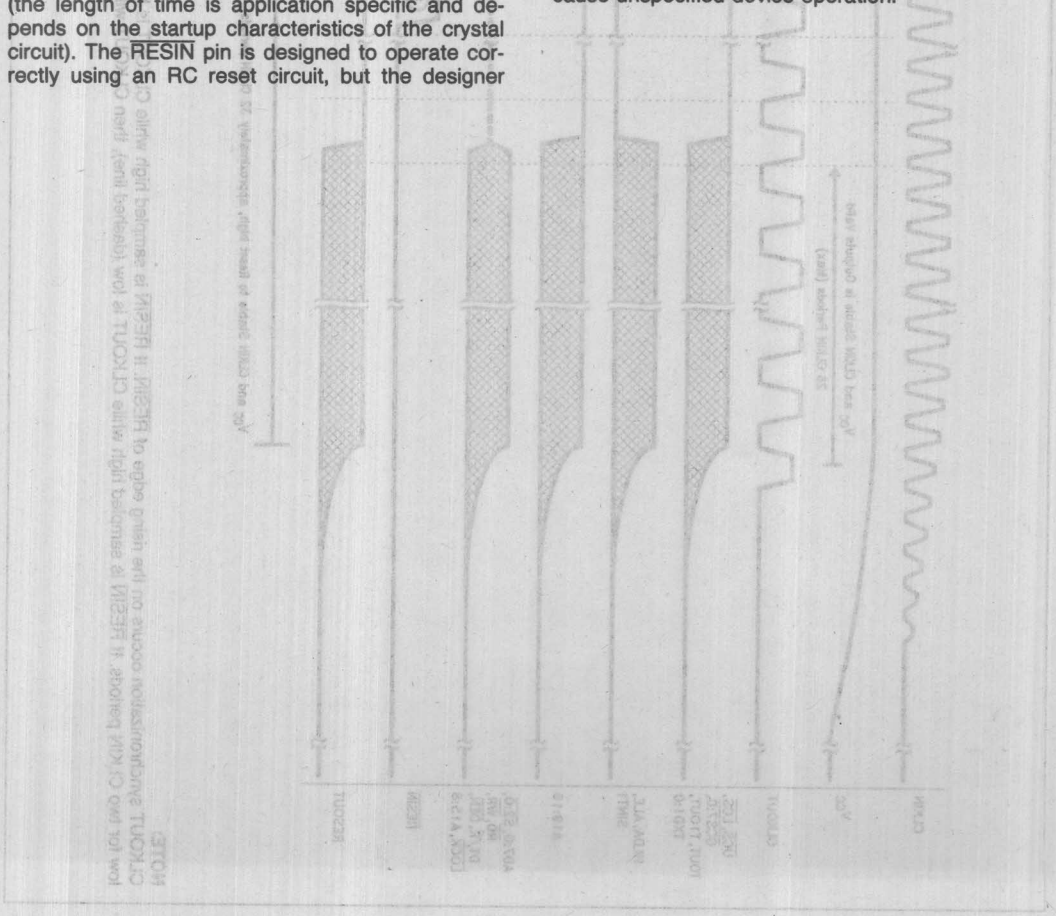
RESET

The 80C188EB will perform a reset operation any time the $\overline{RESIN}$ pin active. The $\overline{RESIN}$ pin is actually synchronized before it is presented internally, which means that the clock must be operating before a reset can take effect. From a power-on state, $\overline{RESIN}$ must be held active (low) in order to guarantee correct initialization of the 80C188EB. **Failure to provide $\overline{RESIN}$ while the device is powering up will result in unspecified operation of the device.**

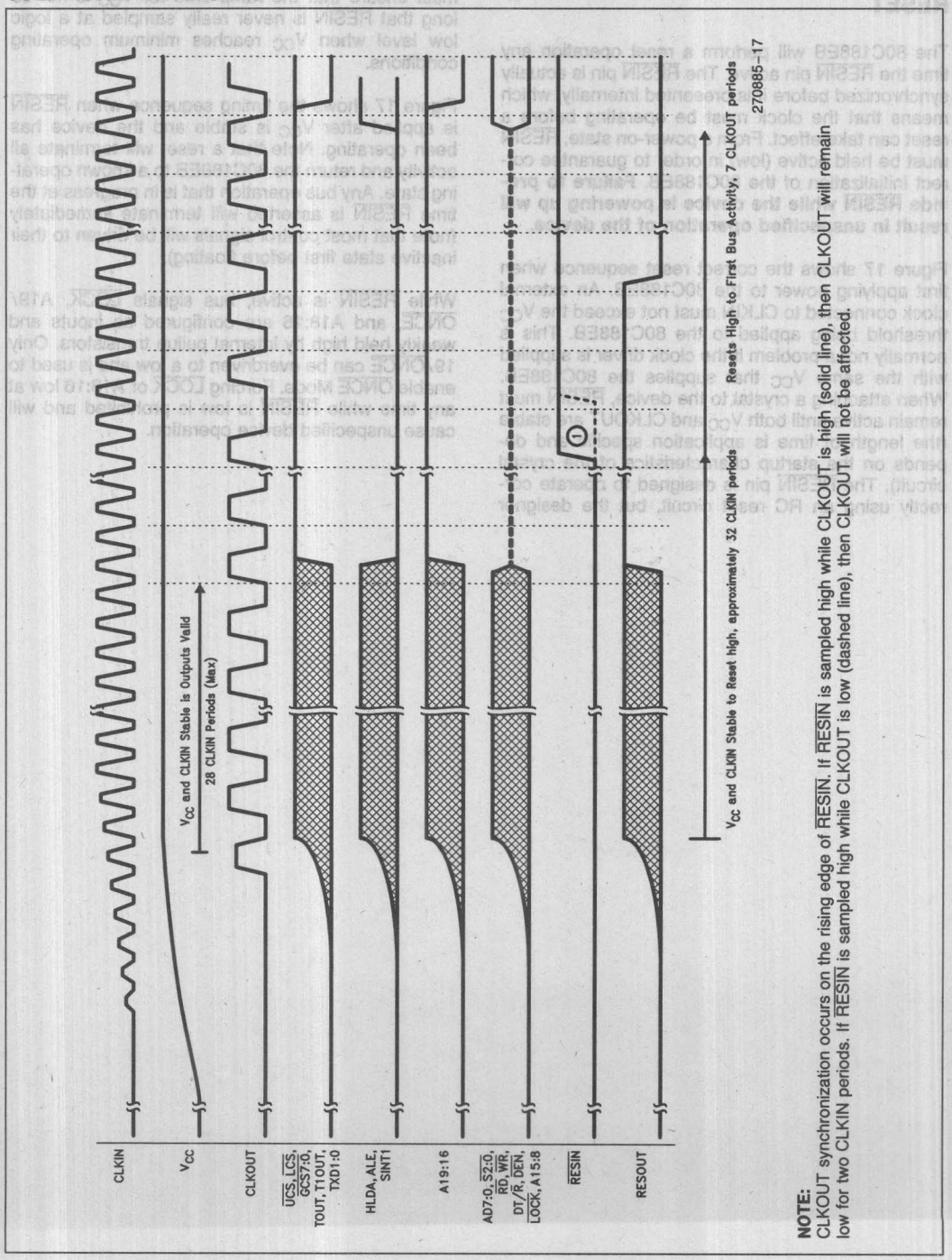
Figure 17 shows the correct reset sequence when first applying power to the 80C188EB. An external clock connected to CLKIN must not exceed the V_{CC} threshold being applied to the 80C188EB. This is normally not a problem if the clock driver is supplied with the same V_{CC} that supplies the 80C188EB. When attaching a crystal to the device, $\overline{RESIN}$ must remain active until both V_{CC} and CLKOUT are stable (the length of time is application specific and depends on the startup characteristics of the crystal circuit). The $\overline{RESIN}$ pin is designed to operate correctly using an RC reset circuit, but the designer must ensure that the ramp time for V_{CC} is not so long that $\overline{RESIN}$ is never really sampled at a logic low level when V_{CC} reaches minimum operating conditions.

Figure 17 shows the timing sequence when $\overline{RESIN}$ is applied after V_{CC} is stable and the device has been operating. Note that a reset will terminate all activity and return the 80C188EB to a known operating state. Any bus operation that is in progress at the time $\overline{RESIN}$ is asserted will terminate immediately (note that most control signals will be driven to their inactive state first before floating).

While $\overline{RESIN}$ is active, bus signals $\overline{LOCK}$, A19/$\overline{ONCE}$, and A18:16 are configured as inputs and weakly held high by internal pullup transistors. Only 19/$\overline{ONCE}$ can be overdriven to a low and is used to enable $\overline{ONCE}$ Mode. Forcing $\overline{LOCK}$ or A18:16 low at any time while $\overline{RESIN}$ is low is prohibited and will cause unspecified device operation.



COLD RESET WAVEFORMS



NOTE:
CLKOUT synchronization occurs on the rising edge of $\overline{RESIN}$. If $\overline{RESIN}$ is sampled high while CLKOUT is high (solid line), then CLKOUT will remain low for two CLKIN periods. If $\overline{RESIN}$ is sampled high while CLKOUT is low (dashed line), then CLKOUT will not be affected.

Figure 17

WARM RESET WAVEFORMS

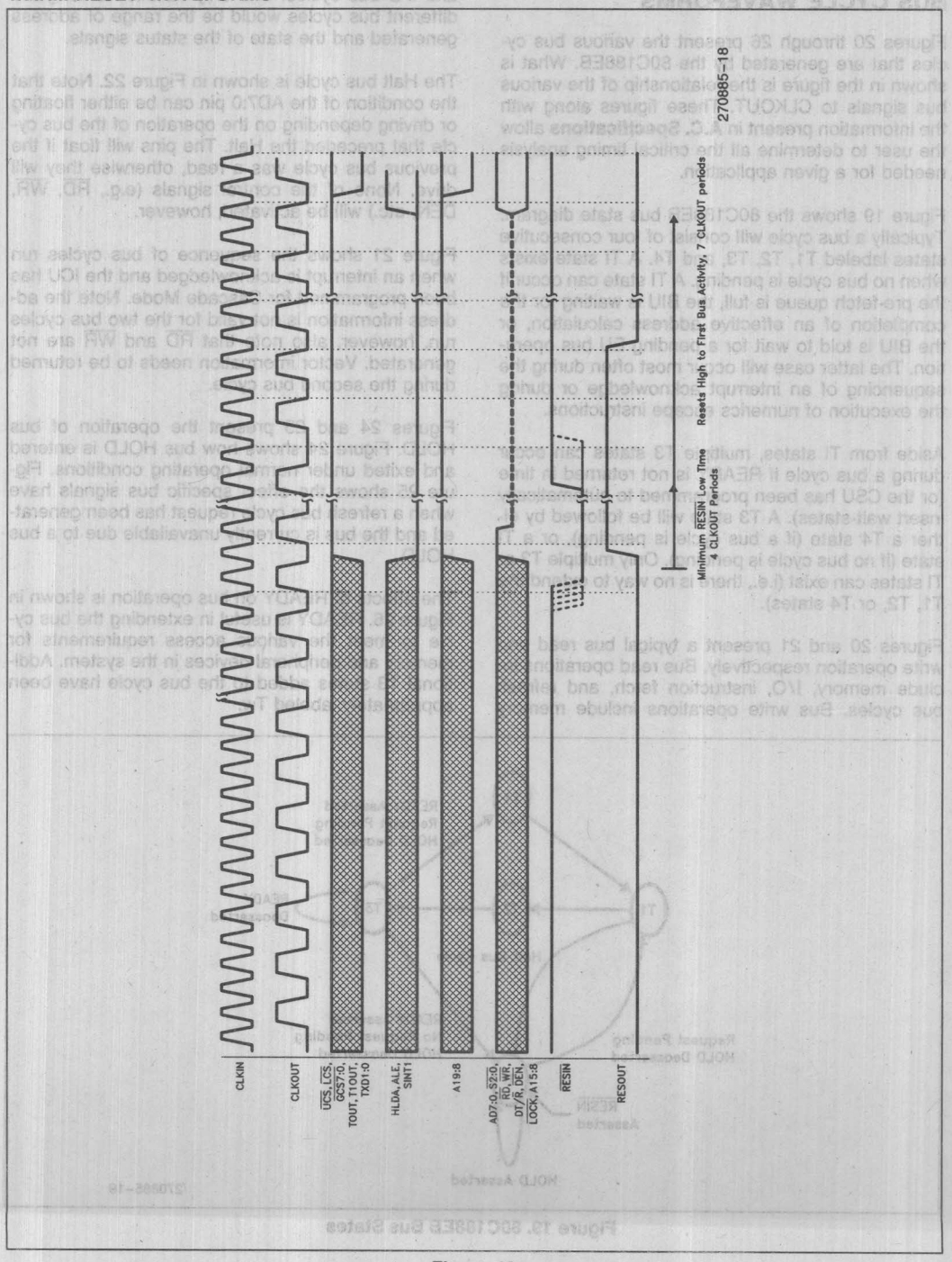


Figure 18

BUS CYCLE WAVEFORMS

Figures 20 through 26 present the various bus cycles that are generated by the 80C188EB. What is shown in the figure is the relationship of the various bus signals to CLKOUT. These figures along with the information present in **A.C. Specifications** allow the user to determine all the critical timing analysis needed for a given application.

Figure 19 shows the 80C188EB bus state diagram. Typically a bus cycle will consist of four consecutive states labeled T1, T2, T3, and T4. A TI state exists when no bus cycle is pending. A TI state can occur if the pre-fetch queue is full, the BIU is waiting for the completion of an effective address calculation, or the BIU is told to wait for a pending EU bus operation. The latter case will occur most often during the sequencing of an interrupt acknowledge or during the execution of numerics escape instructions.

Aside from TI states, multiple T3 states can occur during a bus cycle if READY is not returned in time (or the CSU has been programmed to automatically insert wait-states). A T3 state will be followed by either a T4 state (if a bus cycle is pending), or a TI state (if no bus cycle is pending). Only multiple T3 or TI states can exist (i.e., there is no way to extend the T1, T2, or T4 states).

Figures 20 and 21 present a typical bus read and write operation respectively. Bus read operations include memory, I/O, instruction fetch, and refresh bus cycles. Bus write operations include memory and I/O bus cycles. The only variation among the different bus cycles would be the range of address generated and the state of the status signals.

The Halt bus cycle is shown in Figure 22. Note that the condition of the AD7:0 pin can be either floating or driving depending on the operation of the bus cycle that preceded the Halt. The pins will float if the previous bus cycle was a read, otherwise they will drive. None of the control signals (e.g., $\overline{RD}$, $\overline{WR}$, $\overline{DEN}$, etc.) will be activated, however.

Figure 21 shows the sequence of bus cycles run when an interrupt is acknowledged and the ICU has been programmed for Cascade Mode. Note the address information is not valid for the two bus cycles run, however, also note that $\overline{RD}$ and $\overline{WR}$ are not generated. Vector information needs to be returned during the second bus cycle.

Figures 24 and 25 present the operation of bus HOLD. Figure 24 shows how bus HOLD is entered and exited under normal operating conditions. Figure 25 shows the effect specific bus signals have when a refresh bus cycle request has been generated and the bus is currently unavailable due to a bus HOLD.

The effects of READY on bus operation is shown in Figure 26. READY is useful in extending the bus cycle to meet the various access requirements for memory and peripheral devices in the system. Additional T3 states added to the bus cycle have been appropriately labeled Tw.

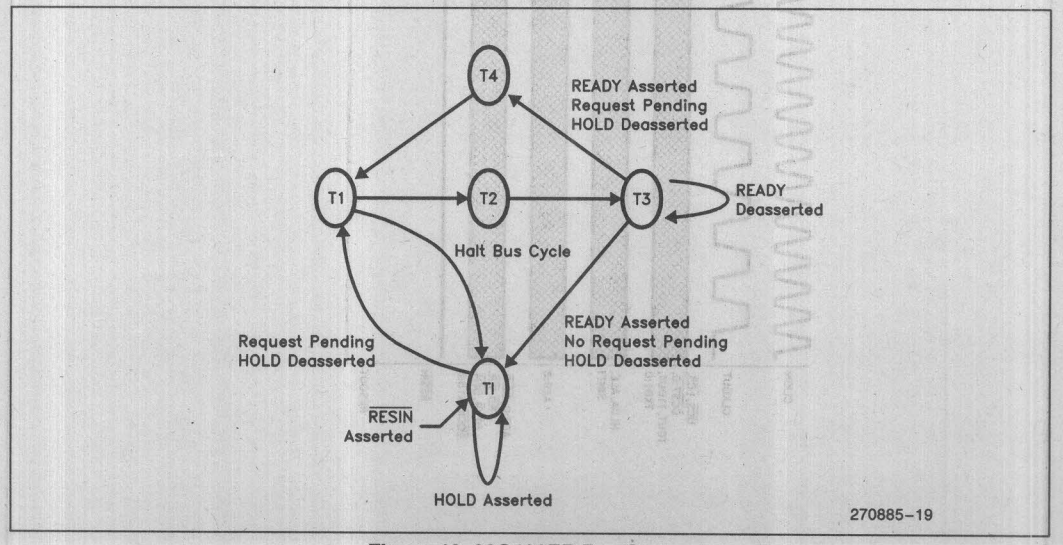


Figure 19. 80C188EB Bus States

BUS CYCLE WAVEFORMS

MEMORY READ, I/O READ, INSTRUCTION FETCH, AND REFRESH WAVEFORM

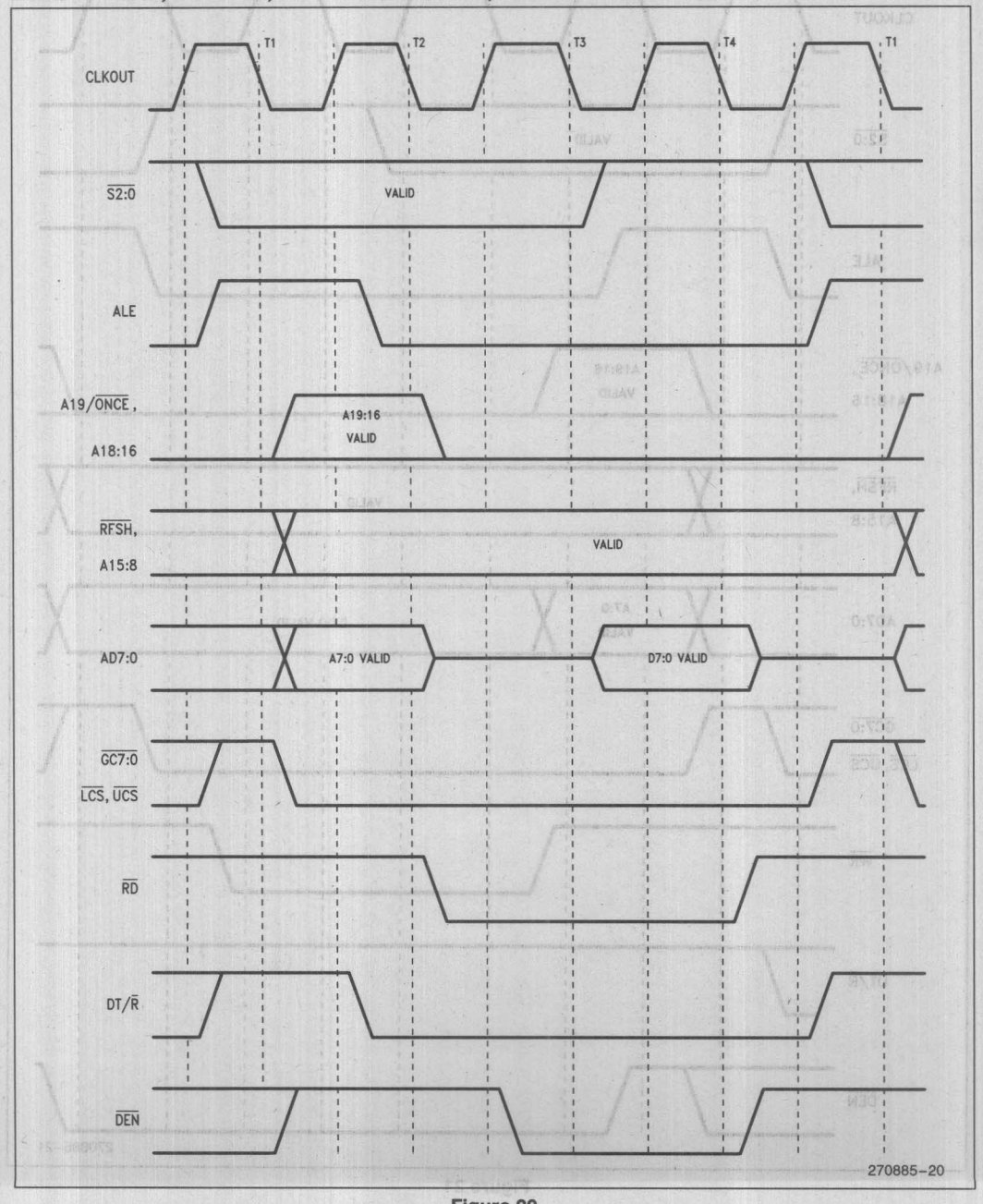


Figure 20

MEMORY WRITE AND I/O WRITE CYCLE WAVEFORM

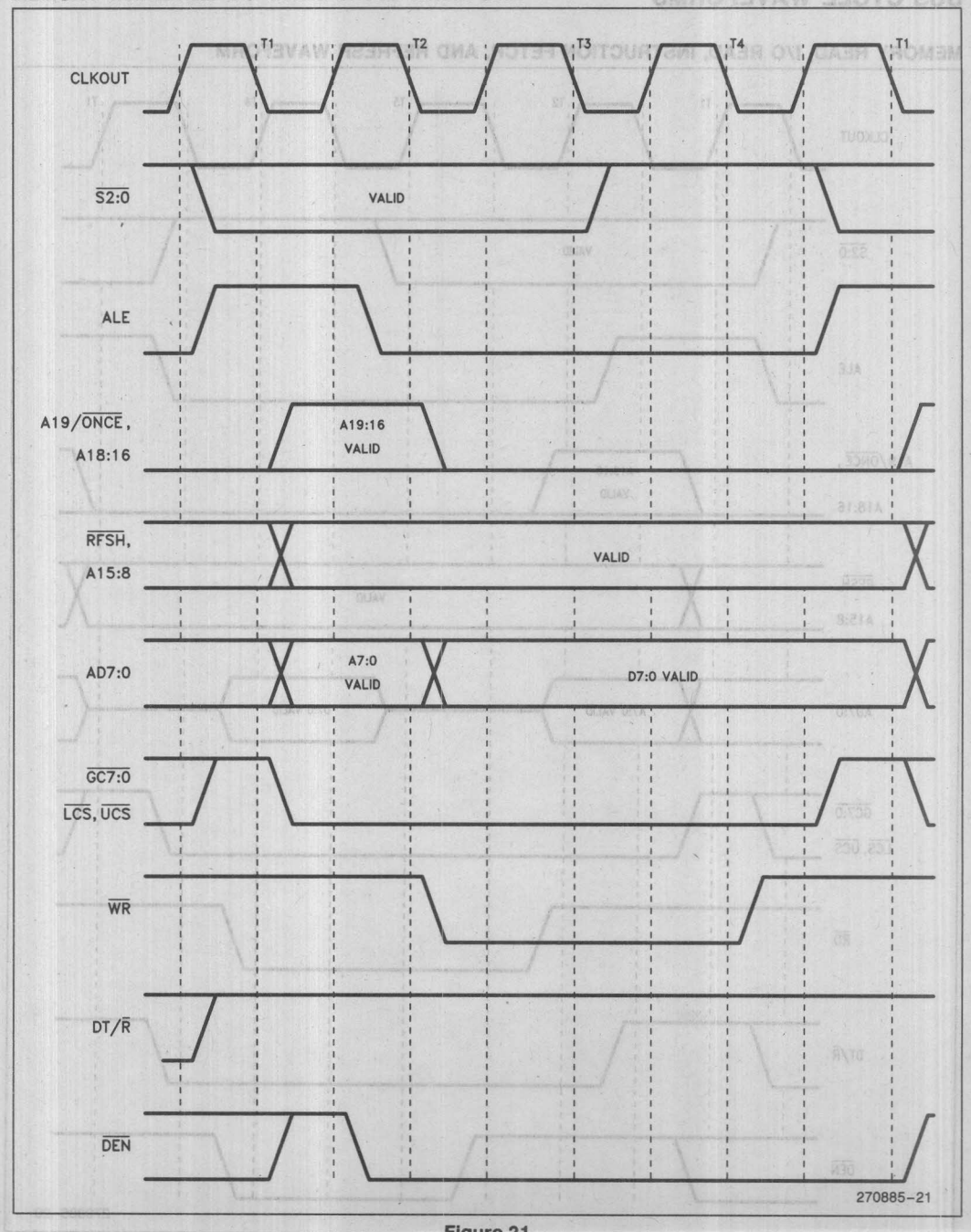
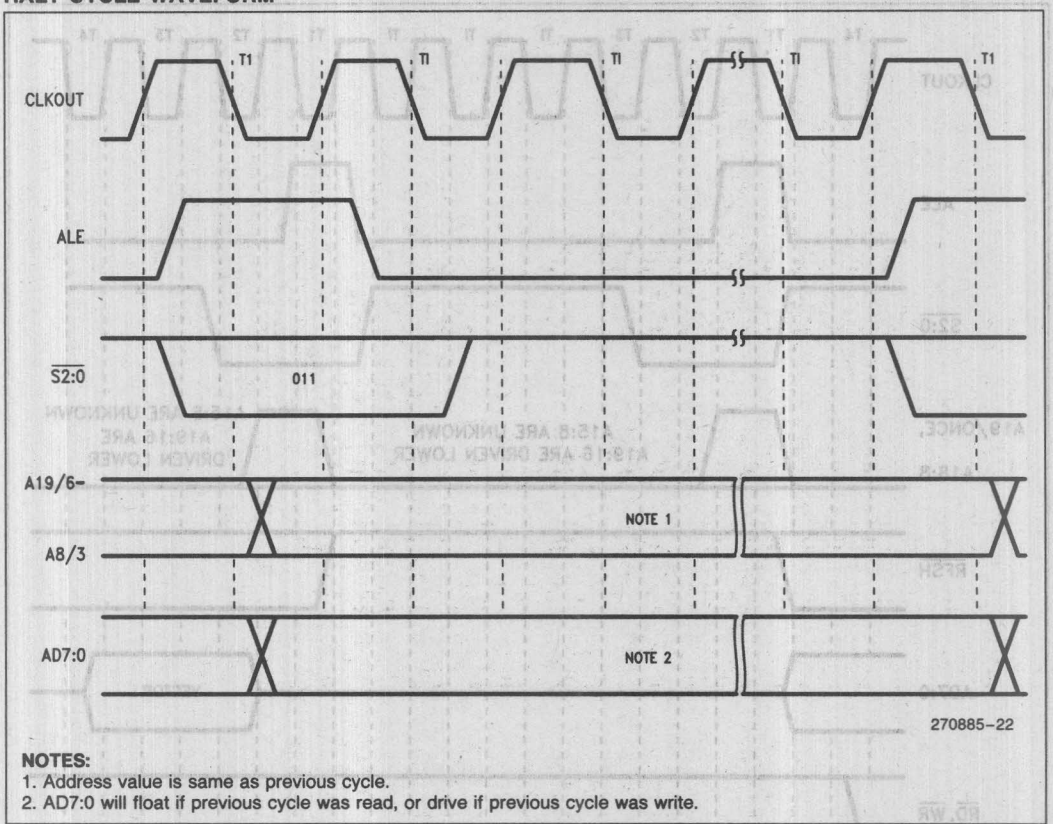


Figure 21

HALT CYCLE WAVEFORM



NOTES:
1. Address value is same as previous cycle.
2. AD7:0 will float if previous cycle was read, or drive if previous cycle was write.

Figure 22

CASCADE MODE INTERRUPT ACKNOWLEDGE CYCLE WAVEFORM

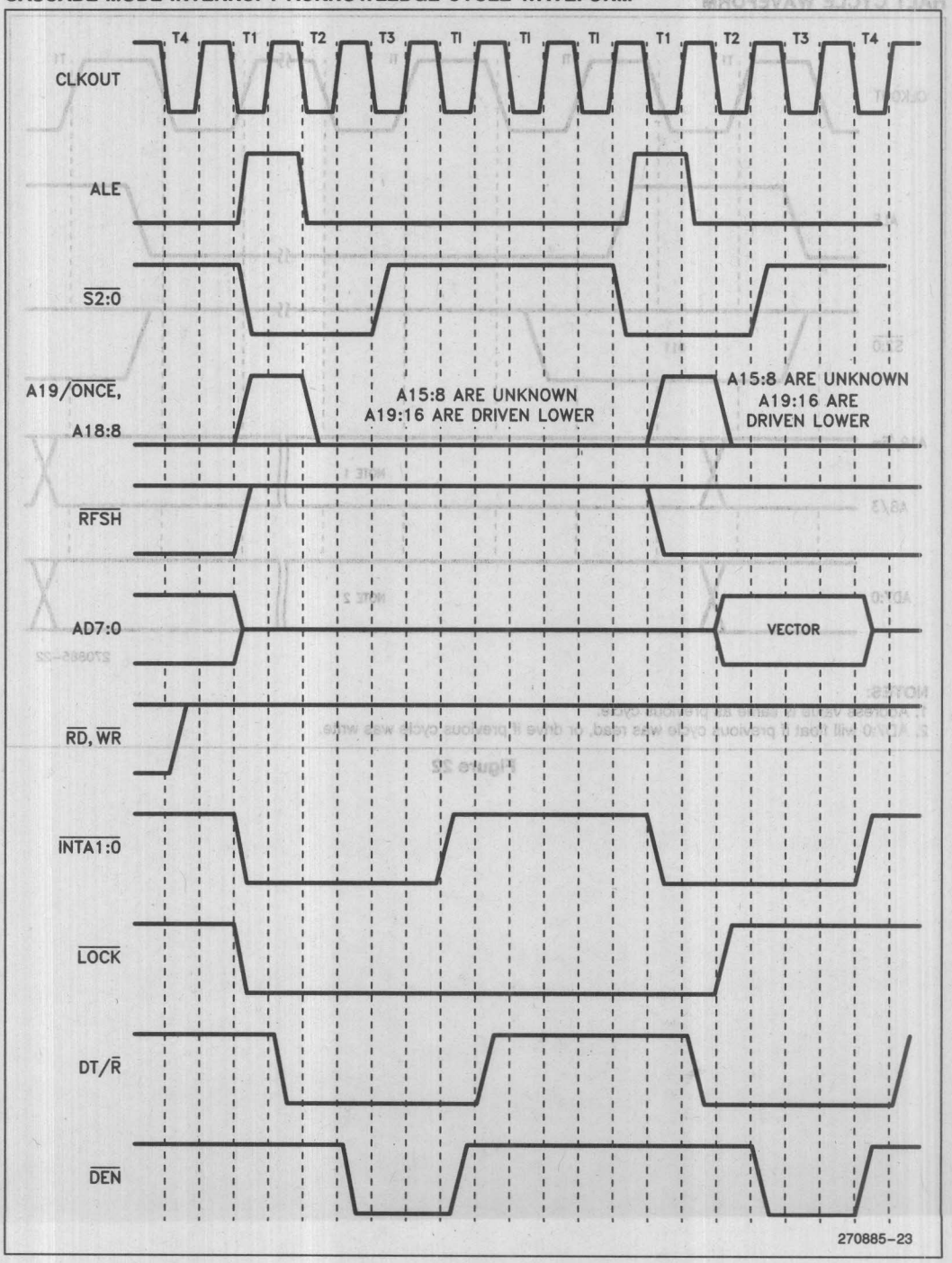


Figure 23

HOLD/HLDA CYCLE WAVEFORMS

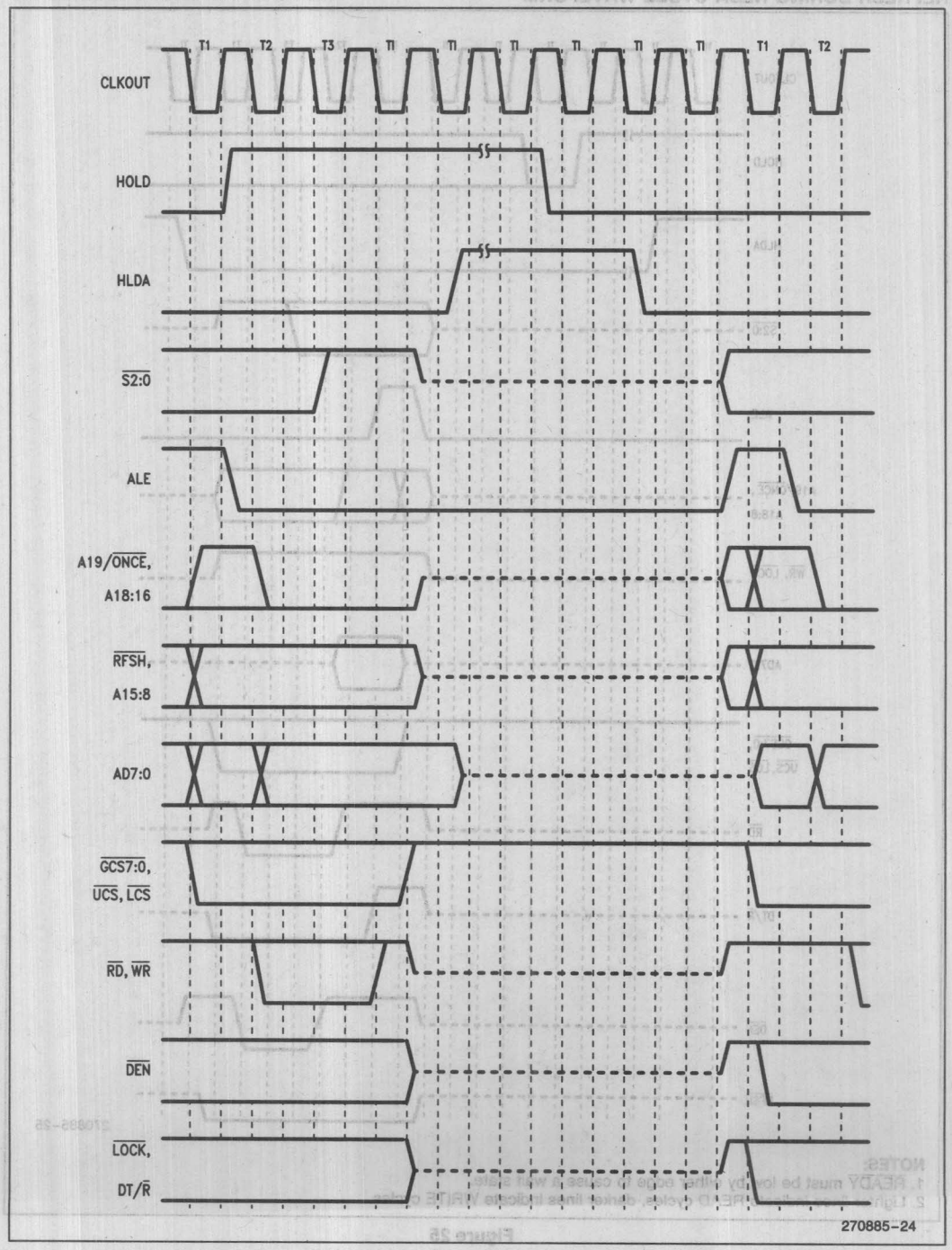
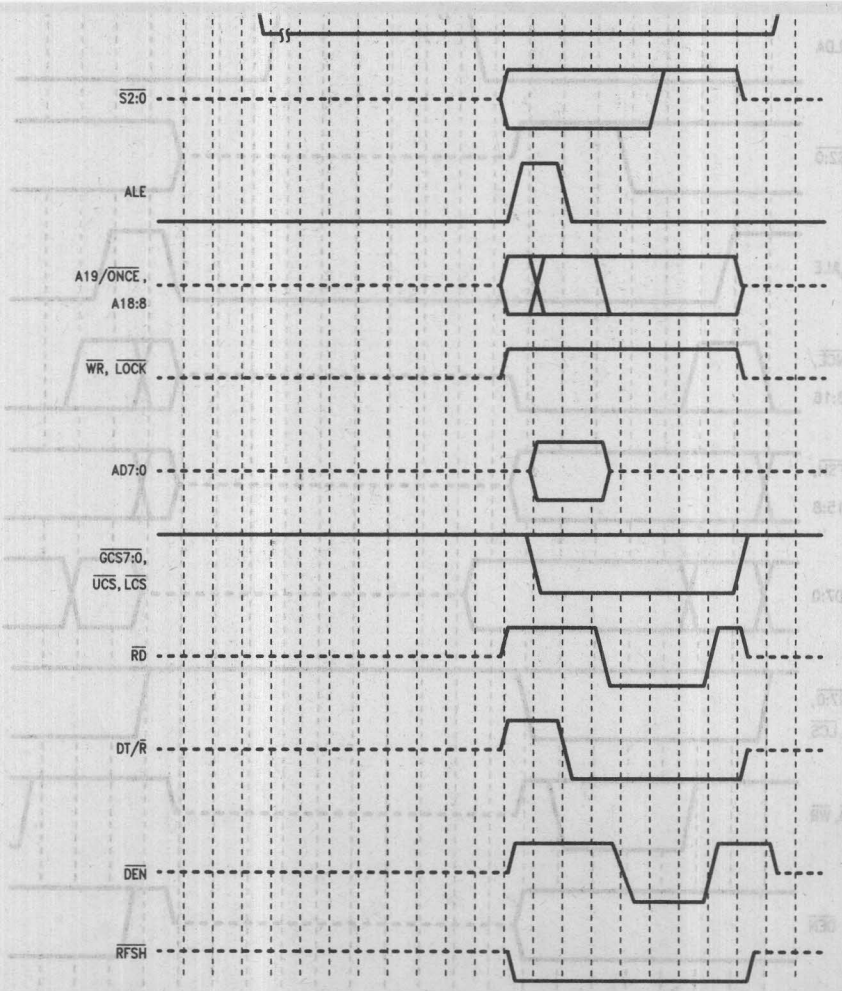


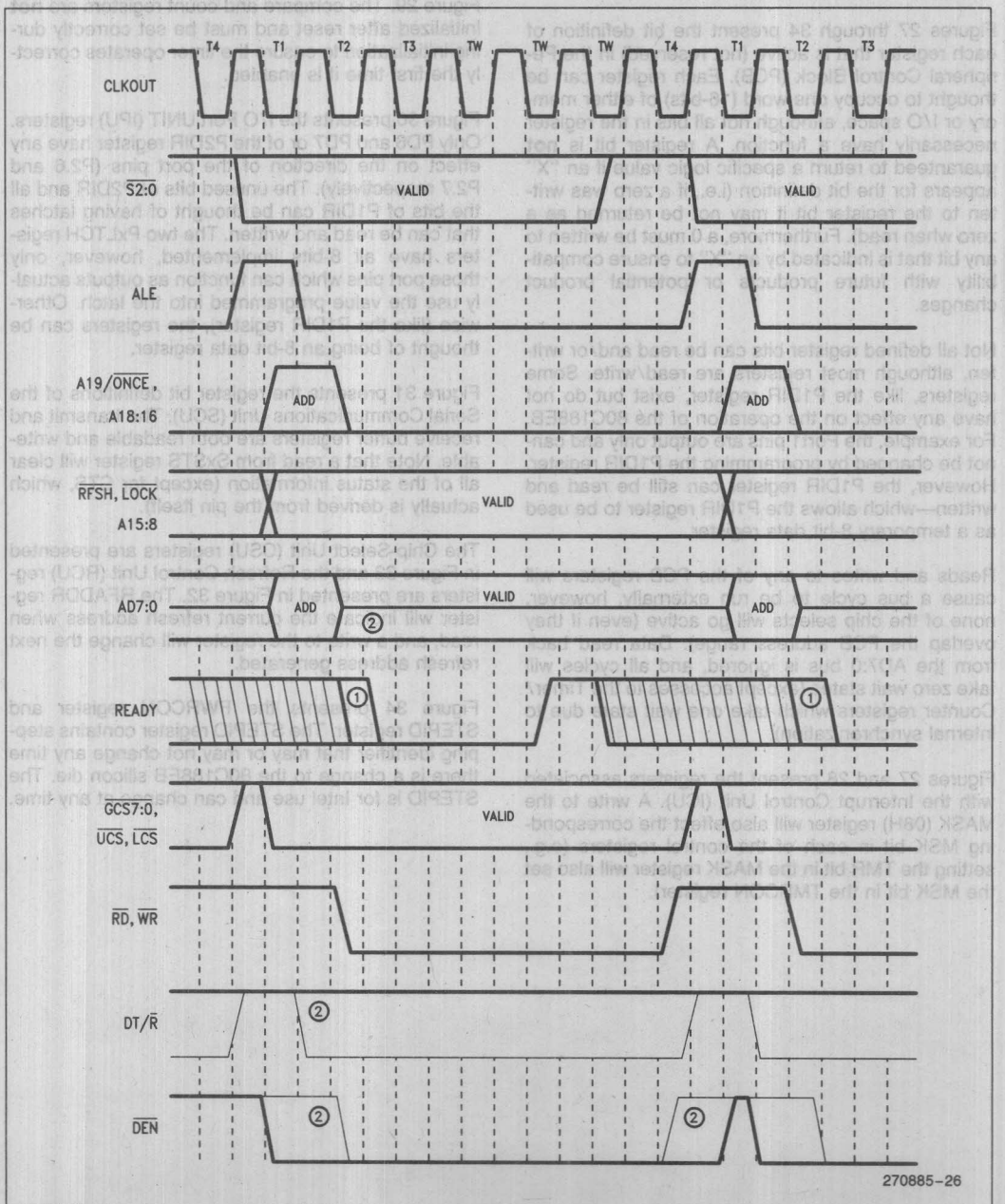
Figure 24



NOTES:
1. READY must be low by either edge to cause a wait state.
2. Lighter lines indicate READ cycles, darker lines indicate WRITE cycles.

Figure 25

READY CYCLE WAVEFORM



NOTES:
1. READY must be low by either edge to cause a wait state.
2. Lighter lines indicate READ cycles, darker lines indicate WRITE cycles.

Figure 26

REGISTER BIT SUMMARY

Figures 27 through 34 present the bit definition of each register that is active (not reserved) in the Peripheral Control Block (PCB). Each register can be thought to occupy one word (16-bits) of either memory or I/O space, although not all bits in the register necessarily have a function. A register bit is **not** guaranteed to return a specific logic value if an "X" appears for the bit definition (i.e., if a zero was written to the register bit it may not be returned as a zero when read). Furthermore, a 0 must be written to any bit that is indicated by an "X" to ensure compatibility with future products or potential product changes.

Not all defined register bits can be read and/or written, although most registers are read/write. Some registers, like the P1DIR register, exist but do not have any effect on the operation of the 80C188EB. For example, the Port1 pins are output only and cannot be changed by programming the P1DIR register. However, the P1DIR register can still be read and written—which allows the P1DIR register to be used as a temporary 8-bit data register.

Reads and writes to any of the PCB registers will cause a bus cycle to be run externally, however, none of the chip selects will go active (even if they overlap the PCB address range). Data read back from the AD7:0 bus is ignored, and all cycles will take zero wait states (except accesses to the Timer/Counter registers which take one wait state due to internal synchronization).

Figures 27 and 28 present the registers associated with the Interrupt Control Unit (ICU). A write to the MASK (08H) register will also effect the corresponding MSK bit in each of the control registers (e.g., setting the TMR bit in the MASK register will also set the MSK bit in the TMRCON register).

The Timer/Counter Unit registers are presented in Figure 29. The compare and count registers are **not** initialized after reset and must be set correctly during initialization to ensure the timer operates correctly the first time it is enabled.

Figure 30 presents the I/O Port UNIT (IPU) registers. Only PD6 and PD7 or of the P2DIR register have any effect on the direction of the port pins (P2.6 and P2.7 respectively). The unused bits of P2DIR and all the bits of P1DIR can be thought of having latches that can be read and written. The two PxLTCH registers have all 8-bits implemented, however, only those port pins which can function as outputs actually use the value programmed into the latch. Otherwise (like the P1DIR register), the registers can be thought of being an 8-bit data register.

Figure 31 presents the register bit definitions of the Serial Communications Unit (SCU). The transmit and receive buffer registers are both readable and writeable. Note that a read from SxSTS register will clear all of the status information (except for CTS, which actually is derived from the pin itself).

The Chip-Select Unit (CSU) registers are presented in Figure 33 and the Refresh Control Unit (RCU) registers are presented in Figure 32. The RFADDR register will indicate the current refresh address when read, and a write to the register will change the next refresh address generated.

Figure 34 presents the PWRCON register and STEPID register. The STEPID register contains stepping identifier that may or may not change any time there is a change to the 80C188EB silicon die. The STEPID is for Intel use and can change at any time.

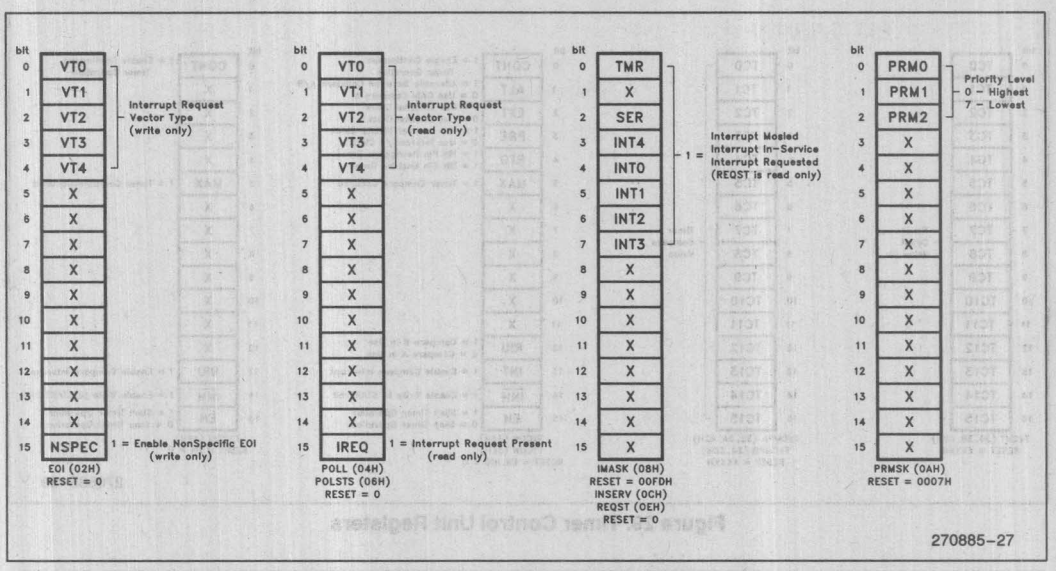


Figure 27. Interrupt Control Unit Registers

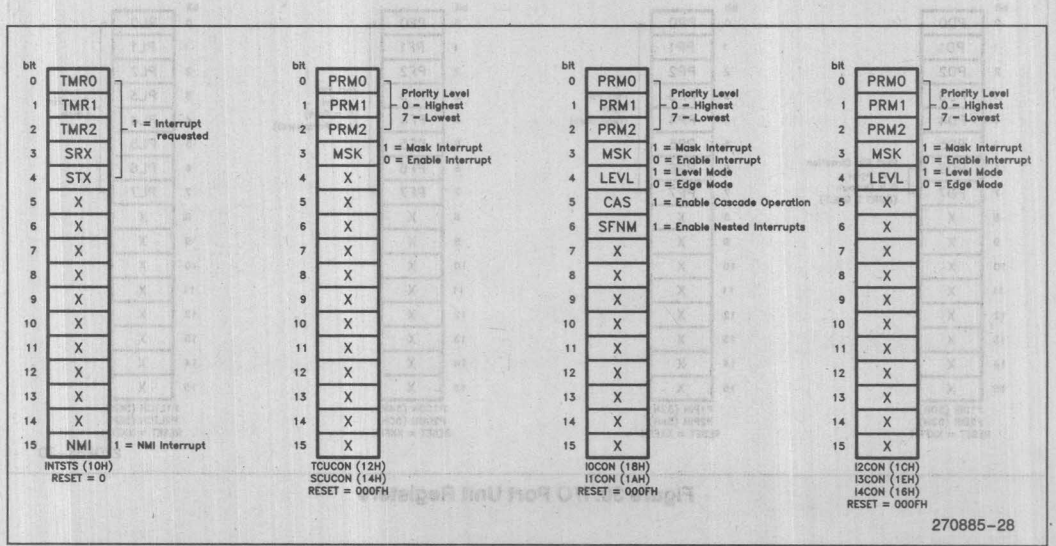


Figure 28. Interrupt Control Unit Registers

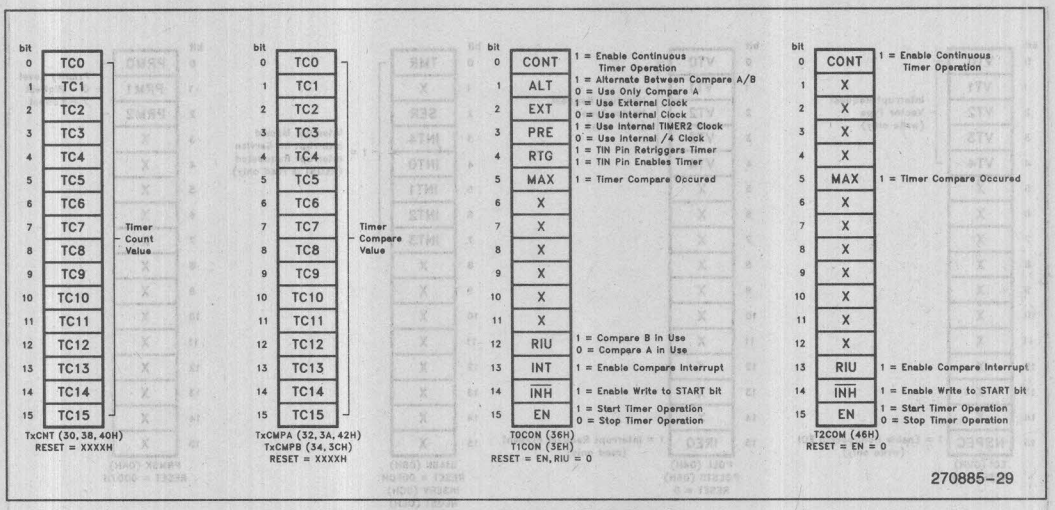


Figure 29. Timer Control Unit Registers

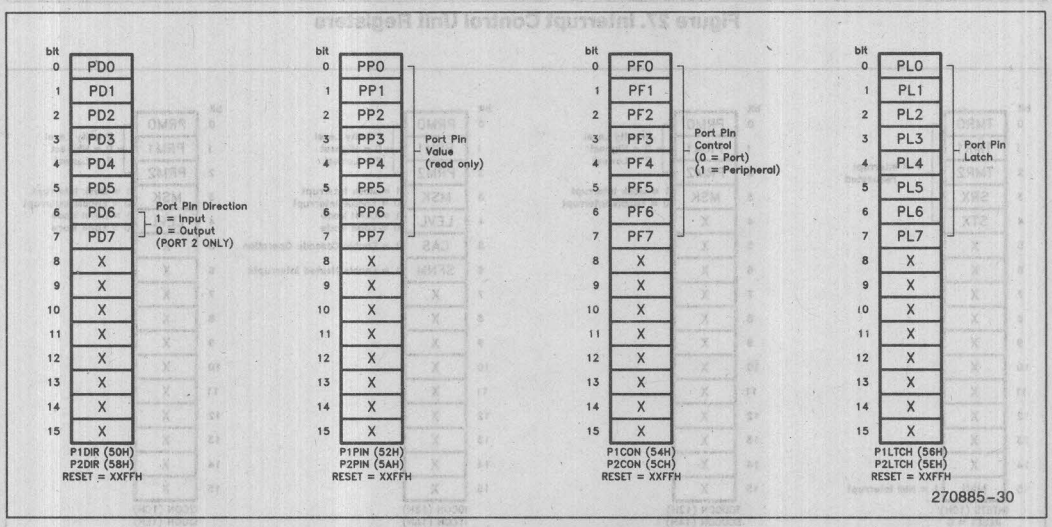


Figure 30. I/O Port Unit Registers

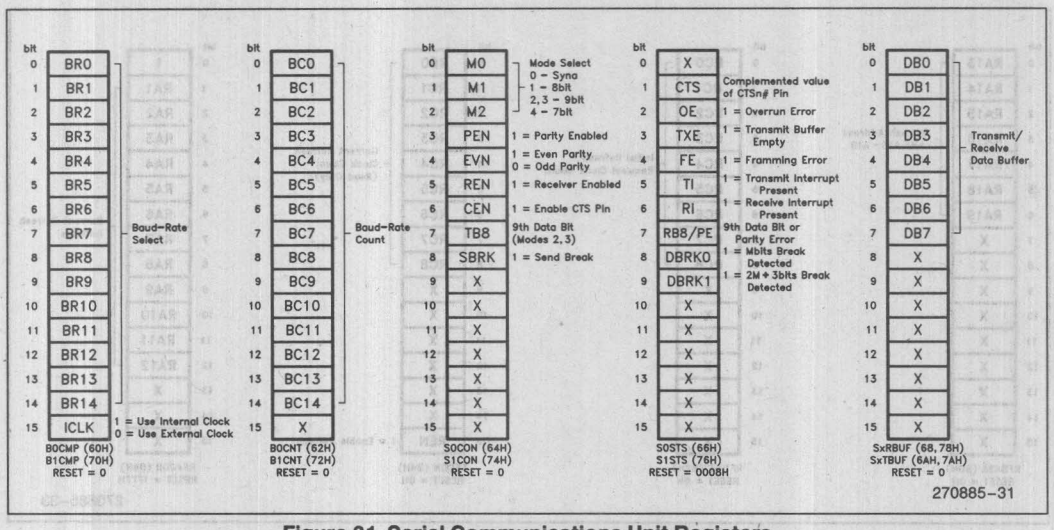


Figure 31. Serial Communications Unit Registers

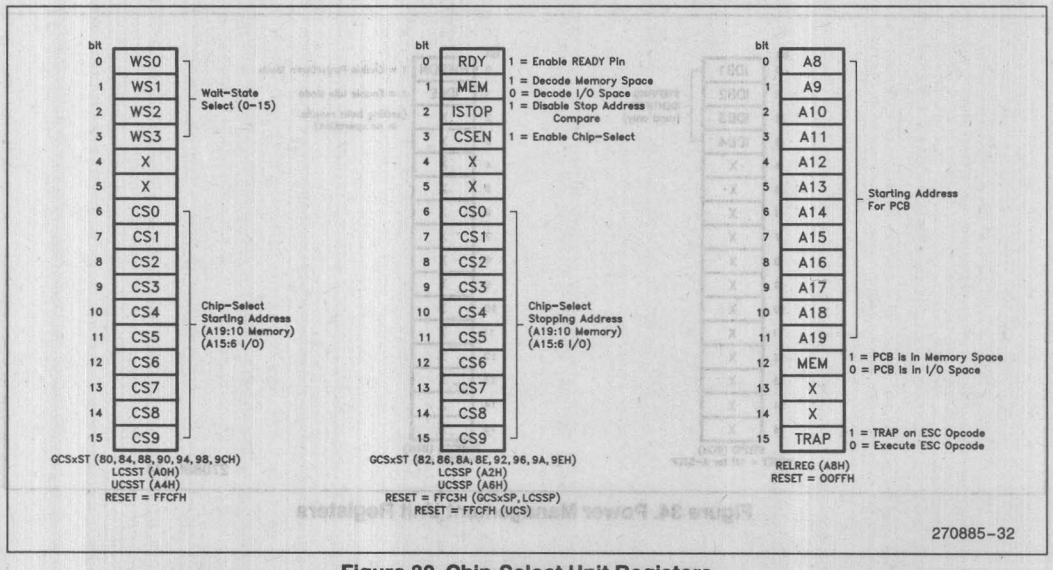


Figure 32. Chip-Select Unit Registers

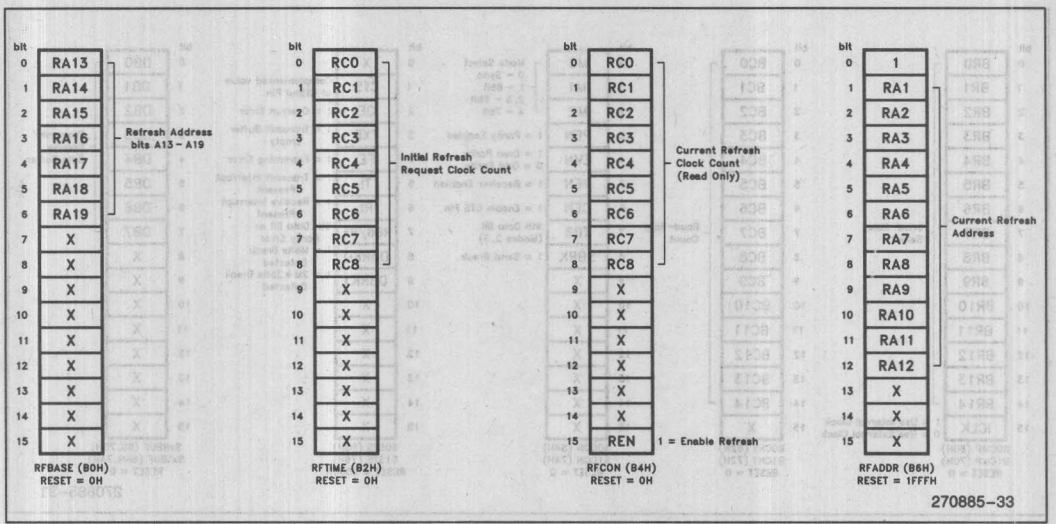


Figure 33. Refresh Control Unit Registers

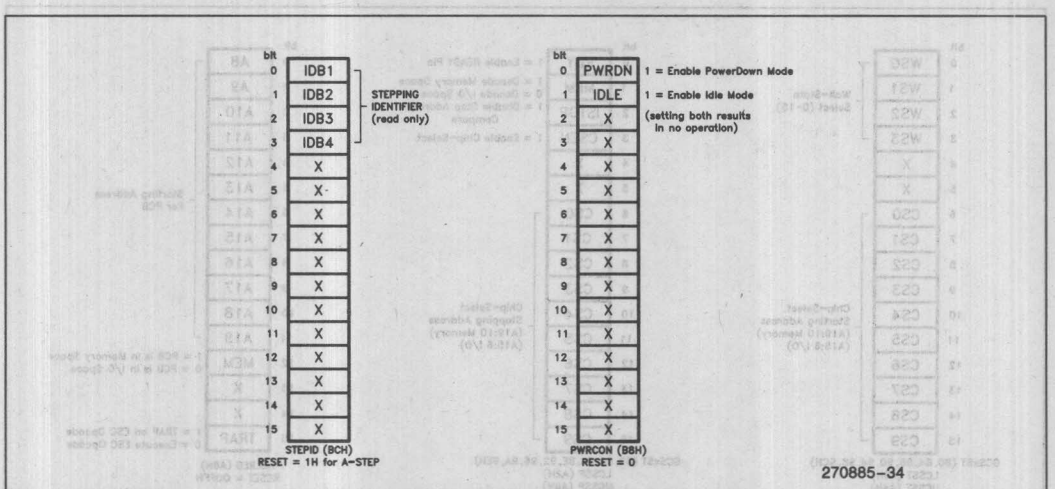


Figure 34. Power Management Unit Registers

80C188EB EXECUTION TIMINGS

A determination of 80C188EB program execution timing must consider the bus cycles necessary to prefetch instructions as well as the number of execution unit cycles necessary to execute instructions. The following instruction timings represent the minimum execution time in clock cycles for each instruction. The timings given are based on the following assumptions:

- The opcode, along with any data or displacement required for execution of a particular instruction, has been prefetched and resides in the queue at the time it is needed.
- No wait states or bus HOLDs occur.

All instructions which involve memory accesses can require one or two additional clocks above the minimum timings shown due to the asynchronous handshake between the bus interface unit (BIU) and execution unit.

All jumps and calls include the time required to fetch the opcode of the next instruction at the destination address.

The 80C188EB 8-bit BIU is noticeably limited in its performance relative to the execution unit. A sufficient number of prefetched bytes may not reside in the prefetch queue much of the time. Therefore, actual program execution time will be substantially greater than that derived from adding the instruction timings shown.

INSTRUCTION SET SUMMARY

Function	Format				Clock Cycles	Comments
DATA TRANSFER						
MOV = Move:						
Register to Register/Memory	1000100w	mod reg r/m			2/12	
Register/memory to register	1000101w	mod reg r/m			2/9	
Immediate to register/memory	1100011w	mod 000 r/m	data	data if w=1	12–13	8/16-bit
Immediate to register	1011w reg	data	data if w=1		3–4	8/16-bit
Memory to accumulator	1010000w	addr-low	addr-high		8	
Accumulator to memory	1010001w	addr-low	addr-high		9	
Register/memory to segment register	10001110	mod 0 reg r/m			2/9	
Segment register to register/memory	10001100	mod 0 reg r/m			2/11	
PUSH = Push:						
Memory	11111111	mod 1 1 0 r/m			16	
Register	01010 reg				10	
Segment register	000 reg 1 1 0				9	
Immediate	011010s0	data	data if s=0		10	
PUSHA = Push All	01100000				36	
POP = Pop:						
Memory	10001111	mod 0 0 0 r/m			20	
Register	01011 reg				10	
Segment register	000 reg 1 1 1	(reg≠01)			8	
POPA = Pop All	01100001				51	
XCHG = Exchange:						
Register/memory with register	1000011w	mod reg r/m			4/17	
Register with accumulator	10010 reg				3	
IN = Input from:						
Fixed port	1110010w	port			10	
Variable port	1110110w				8	
OUT = Output to:						
Fixed port	1110011w	port			9	
Variable port	1110111w				7	
XLAT = Translate byte to AL	11010111				11	
LEA = Load EA to register	10001101	mod reg r/m			6	
LDS = Load pointer to DS	11000101	mod reg r/m	(mod≠11)		18	
LES = Load pointer to ES	11000100	mod reg r/m	(mod≠11)		18	
LAHF = Load AH with flags	10011111				2	
SAHF = Store AH into flags	10011110				3	
PUSHF = Push flags	10011100				9	
POPF = Pop flags	10011101				8	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
DATA TRANSFER (Continued)						
SEGMENT = Segment Override:						
CS	00101110				2	
SS	00110110				2	
DS	00111110				2	
ES	00100110				2	
ARITHMETIC						
ADD = Add:						
Reg/memory with register to either	000000dw	mod reg r/m			3/10	
Immediate to register/memory	100000sw	mod 000 r/m	data	data if s w=01	4/16	
Immediate to accumulator	0000010w	data	data if w=1		3/4	8/16-bit
ADC = Add with carry:						
Reg/memory with register to either	000100dw	mod reg r/m			3/10	
Immediate to register/memory	100000sw	mod 010 r/m	data	data if s w=01	4/16	
Immediate to accumulator	0001010w	data	data if w=1		3/4	8/16-bit
INC = Increment:						
Register/memory	1111111w	mod 000 r/m			3/15	
Register	01000 reg				3	
SUB = Subtract:						
Reg/memory and register to either	001010dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 101 r/m	data	data if s w=01	4/16	
Immediate from accumulator	0010110w	data	data if w=1		3/4	8/16-bit
SBB = Subtract with borrow:						
Reg/memory and register to either	000110dw	mod reg r/m			3/10	
Immediate from register/memory	100000sw	mod 011 r/m	data	data if s w=01	4/16	
Immediate from accumulator	0001110w	data	data if w=1		3/4	8/16-bit
DEC = Decrement						
Register/memory	1111111w	mod 001 r/m			3/15	
Register	01001 reg				3	
CMP = Compare:						
Register/memory with register	0011101w	mod reg r/m			3/10	
Register with register/memory	0011100w	mod reg r/m			3/10	
Immediate with register/memory	100000sw	mod 111 r/m	data	data if s w=01	3/10	
Immediate with accumulator	0011110w	data	data if w=1		3/4	8/16-bit
NEG = Change sign register/memory	1111011w	mod 011 r/m			3/10	
AAA = ASCII adjust for add	00110111				8	
DAA = Decimal adjust for add	00100111				4	
AAS = ASCII adjust for subtract	00111111				7	
DAS = Decimal adjust for subtract	00101111				4	
MUL = Multiply (unsigned):	1111011w	mod 100 r/m				
Register-Byte					26–28	
Register-Word					35–37	
Memory-Byte					32–34	
Memory-Word					41–43	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
ARITHMETIC (Continued)			
IMUL = Integer multiply (signed):	1 1 1 1 0 1 1 w | mod 1 0 1 r/m		
Register-Byte		25–28	
Register-Word		34–37	
Memory-Byte		31–34	
Memory-Word		40–43	
IMUL = Integer Immediate multiply (signed)	0 1 1 0 1 0 s 1 | mod reg r/m | data | data if s=0	22–25/ 29–32	
DIV = Divide (unsigned):	1 1 1 1 0 1 1 w | mod 1 1 0 r/m		
Register-Byte		29	
Register-Word		38	
Memory-Byte		35	
Memory-Word		44	
IDIV = Integer divide (signed):	1 1 1 1 0 1 1 w | mod 1 1 1 r/m		
Register-Byte		44–52	
Register-Word		53–61	
Memory-Byte		50–58	
Memory-Word		59–67	
AAM = ASCII adjust for multiply	1 1 0 1 0 1 0 0 | 0 0 0 0 1 0 1 0	19	
AAD = ASCII adjust for divide	1 1 0 1 0 1 0 1 | 0 0 0 0 1 0 1 0	15	
CBW = Convert byte to word	1 0 0 1 1 0 0 0	2	
CWD = Convert word to double word	1 0 0 1 1 0 0 1	4	
LOGIC			
Shift/Rotate Instructions:			
Register/Memory by 1	1 1 0 1 0 0 0 w | mod TTT r/m	2/15	
Register/Memory by CL	1 1 0 1 0 0 1 w | mod TTT r/m	5+n/17+n	
Register/Memory by Count	1 1 0 0 0 0 0 w | mod TTT r/m | count	5+n/17+n	
	TTT Instruction 0 0 0 ROL 0 0 1 ROR 0 1 0 RCL 0 1 1 RCR 1 0 0 SHL/SAL 1 0 1 SHR 1 1 1 SAR		
AND = **And:**			
Reg/memory and register to either	0 0 1 0 0 0 d w | mod reg r/m	3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 1 0 0 r/m | data | data if w=1	4/16	
Immediate to accumulator	0 0 1 0 0 1 0 w | data | data if w=1	3/4	8/16-bit
TEST = **And function to flags, no result:**			
Register/memory and register	1 0 0 0 0 1 0 w | mod reg r/m	3/10	
Immediate data and register/memory	1 1 1 1 0 1 1 w | mod 0 0 0 r/m | data | data if w=1	4/10	
Immediate data and accumulator	1 0 1 0 1 0 0 w | data | data if w=1	3/4	8/16-bit
OR = **Or:**			
Reg/memory and register to either	0 0 0 0 1 0 d w | mod reg r/m	3/10	
Immediate to register/memory	1 0 0 0 0 0 0 w | mod 0 0 1 r/m | data | data if w=1	4/16	
Immediate to accumulator	0 0 0 0 1 1 0 w | data | data if w=1	3/4	8/16-bit

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
LOGIC (Continued)						
XOR = Exclusive or:						
Reg/memory and register to either	001100dw	mod reg r/m			3/10	
Immediate to register/memory	1000000w	mod 110 r/m	data	data if w=1	4/16	
Immediate to accumulator	0011010w	data	data if w=1		3/4	8/16-bit
NOT = Invert register/memory	1111011w	mod 010 r/m			3/10	
STRING MANIPULATION						
MOVS = Move byte/word	1010010w				14	
CMPS = Compare byte/word	1010011w				22	
SCAS = Scan byte/word	1010111w				15	
LODS = Load byte/wd to AL/AX	1010110w				12	
STOS = Store byte/wd from AL/AX	1010101w				10	
INS = Input byte/wd from DX port	0110110w				14	
OUTS = Output byte/wd to DX port	0110111w				14	
Repeated by count in CX (REP/REPE/REPZ/REPNE/REPNZ)						
MOVS = Move string	11110010	1010010w			8+8n	
CMPS = Compare string	1111001z	1010011w			5+22n	
SCAS = Scan string	1111001z	1010111w			5+15n	
LODS = Load string	11110010	1010110w			6+11n	
STOS = Store string	11110010	1010101w			6+9n	
INS = Input string	11110010	0110110w			8+8n	
OUTS = Output string	11110010	0110111w			8+8n	
CONTROL TRANSFER						
CALL = Call:						
Direct within segment	11101000	disp-low	disp-high		15	
Register/memory indirect within segment	11111111	mod 010 r/m			13/19	
Direct intersegment	10011010	segment offset			23	
		segment selector				
Indirect intersegment	11111111	mod 011 r/m	(mod ≠ 11)		38	
JMP = Unconditional jump:						
Short/long	11101011	disp-low			14	
Direct within segment	11101001	disp-low	disp-high		14	
Register/memory indirect within segment	11111111	mod 100 r/m			11/17	
Direct intersegment	11101010	segment offset			14	
		segment selector				
Indirect intersegment	11111111	mod 101 r/m	(mod ≠ 11)		26	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format				Clock Cycles	Comments
CONTROL TRANSFER (Continued)						
RET = **Return from CALL:**						
Within segment	11000011				16	
Within seg adding immed to SP	11000010	data-low	data-high		18	
Intersegment	11001011				22	
Intersegment adding immediate to SP	11001010	data-low	data-high		25	
JE/JZ = Jump on equal/zero	01110100	disp			4/13	JMP not taken/JMP taken
JL/JNGE = Jump on less/not greater or equal	01111100	disp			4/13	
JLE/JNG = Jump on less or equal/not greater	01111110	disp			4/13	
JB/JNAE = Jump on below/not above or equal	01110010	disp			4/13	
JBE/JNA = Jump on below or equal/not above	01110110	disp			4/13	
JP/JPE = Jump on parity/parity even	01111010	disp			4/13	
JO = Jump on overflow	01110 000	disp			4/13	
JS = Jump on sign	01111000	disp			4/13	
JNE/JNZ = Jump on not equal/not zero	01110101	disp			4/13	
JNL/JGE = Jump on not less/greater or equal	01111101	disp			4/13	
JNLE/JG = Jump on not less or equal/greater	01111111	disp			4/13	
JNB/JAE = Jump on not below/above or equal	01110011	disp			4/13	
JNBE/JA = Jump on not below or equal/above	01110111	disp			4/13	
JNP/JPO = Jump on not par/par odd	01111011	disp			4/13	
JNO = Jump on not overflow	01110001	disp			4/13	
JNS = Jump on not sign	01111001	disp			4/13	
JCXZ = Jump on CX zero	11100011	disp			5/15	
LOOP = Loop CX times	11100010	disp			6/16	LOOP not taken/LOOP taken
LOOPZ/LOOPE = Loop while zero/equal	11100001	disp			6/16	
LOOPNZ/LOOPNE = Loop while not zero/equal	11100000	disp			6/16	
ENTER = Enter Procedure	11001000	data-low	data-high	L		
L = 0					15	
L = 1					25	
L > 1					22+16(n−1)	
LEAVE = Leave Procedure	11001001				8	
INT = **Interrupt:**						
Type specified	11001101	type			47	
Type 3	11001100				45	if INT. taken/ if INT. not taken
INTO = Interrupt on overflow	11001110				48/4	
IRET = Interrupt return	11001111				28	
BOUND = Detect value out of range	01100010	mod reg r/m			33–35	

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

INSTRUCTION SET SUMMARY (Continued)

Function	Format	Clock Cycles	Comments
PROCESSOR CONTROL			
CLC = Clear carry	11111000	2	
CMC = Complement carry	11110101	2	
STC = Set carry	11111001	2	
CLD = Clear direction	11111100	2	
STD = Set direction	11111101	2	
CLI = Clear interrupt	11111010	2	
STI = Set interrupt	11111011	2	
HLT = Halt	11110100	2	
WAIT = Wait	10011011	6	if $\overline{TEST}$ = 0
LOCK = Bus lock prefix	11110000	2	
NOP = No Operation	10010000	3	
	(TTT LLL are opcode to processor extension)		

Shaded areas indicate instructions not available in 8086, 8088 microsystems.

FOOTNOTES

The Effective Address (EA) of the memory operand is computed according to the mod and r/m fields:

if mod = 11 then r/m is treated as a REG field
if mod = 00 then DISP = 0*, disp-low and disp-high are absent
if mod = 01 then DISP = disp-low sign-extended to 16-bits, disp-high is absent
if mod = 10 then DISP = disp-high: disp-low
if r/m = 000 then EA = (BX) + (SI) + DISP
if r/m = 001 then EA = (BX) + (DI) + DISP
if r/m = 010 then EA = (BP) + (SI) + DISP
if r/m = 011 then EA = (BP) + (DI) + DISP
if r/m = 100 then EA = (SI) + DISP
if r/m = 101 then EA = (DI) + DISP
if r/m = 110 then EA = (BP) + DISP*
if r/m = 111 then EA = (BX) + DISP

DISP follows 2nd byte of instruction (before data if required)

*except if mod = 00 and r/m = 110 then EA = disp-high: disp-low.

EA calculation time is 4 clock cycles for all modes, and is included in the execution times given whenever appropriate.

Segment Override Prefix

0	0	1	reg	1	1	0

reg is assigned according to the following:

reg	Segment Register
00	ES
01	CS
10	SS
11	DS

REG is assigned according to the following table:

16-Bit (w = 1)	8-Bit (w = 0)
000 AX	000 AL
001 CX	001 CL
010 DX	010 DL
011 BX	011 BL
100 SP	100 AH
101 BP	101 CH
110 SI	110 DH
111 DI	111 BH

The physical addresses of all operands addressed by the BP register are computed using the SS segment register. The physical addresses of the destination operands of the string primitive operations (those addressed by the DI register) are computed using the ES segment, which may not be overridden.

ERRATA

The 80C188EB has the following known errata that apply to any device with a stepping ID (STEPID) of 0001H.

1. A19/$\overline{ONCE}$ is not latched by the rising edge of $\overline{RESIN}$. A19/$\overline{ONCE}$ must remain active (LOW) at all times to remain in the ONCE™ Mode. Removing A19/$\overline{ONCE}$ after $\overline{RESIN}$ is high will return all output pins to a driving state, however, the 80C188EB will remain in a reset state.
2. During interrupt acknowledge (INTA) bus cycles, the bus controller will ignore the state of the READY pin if the previous bus cycle ignored the state of the READY pin. This errata can only occur if the Chip-Select Unit is being used. All active chip-selects must be programmed to use READY (RDY bit must be programmed to a 1) if wait-states are required for INTA bus cycles.
3. CLKOUT will transition off the **rising** edge of CLKIN rather than the falling edge of CLKIN. This does not affect any bus timings other than T_{CICO}.
4. $\overline{RESIN}$ has a hysterisis of only 130 mV. It is recommended that $\overline{RESIN}$ be driven with a Schmitt triggered device to avoid processor lockup during reset when using an RC circuit.

REVISION HISTORY

This is the first edition of this datasheet.

82188
INTEGRATED BUS CONTROLLER FOR 8086, 8088, 80186, 80188 PROCESSORS

- **Provides Flexibility in System Configurations**
  - **— Supports 8087 Math Coprocessor in 8 MHz 80186 and 80188 Systems**
  - **— Provides a Low-cost Interface for 8086, 8088 Systems to an 82586 LAN Coprocessor or 82730 Text Coprocessor**
- **Facilitates Interface to one or more Multimaster Busses**
- **Supports Multiprocessor, Local Bus Systems**
- **Allows use of 80186/80188 High-Integration Features**
- **3-State, Command Output Drivers**
- **Available in EXPRESS**
  - **— Standard Temperature Range**
  - **— Extended Temperature Range**
- **Available in Plastic DIP or Cerdip Package**

(See Packaging Outlines and Dimensions, Order #231369)

1

The 82188 Integrated Bus Controller (IBC) is a 28-pin HMOS III component for use with 80186, 80188, 8086 and 8088 systems. The IBC provides command and control timing signals plus a configurable $\overline{RQ}/\overline{GT} \longleftrightarrow$ HOLD-HLDA converter. The device may be used to interface an 8087 Math Coprocessor with an 80186 or 80188 Processor. Also, an 82586 Local Area Network (LAN) Coprocessor or 82730 Text Coprocessor may be interfaced to an 8086 or 8088 with the IBC.

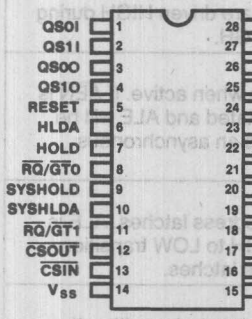


Figure 1.
82188 Pin Configuration

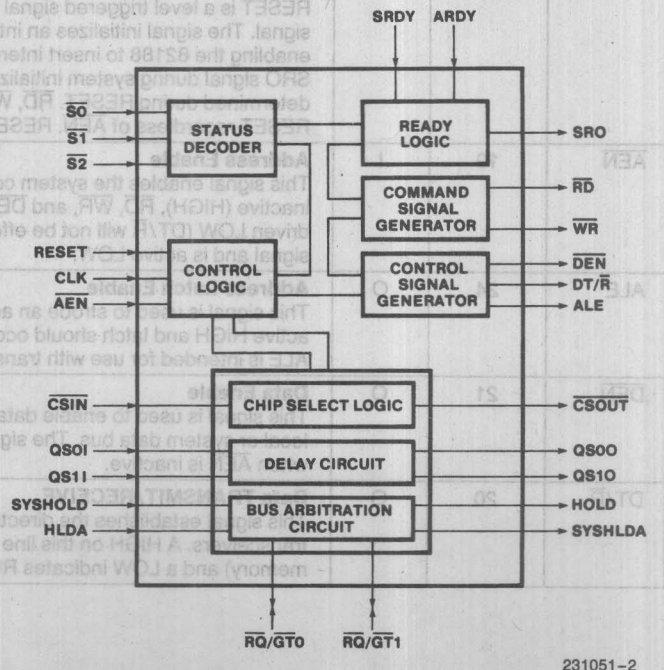


Figure 2.
82188 Block Diagram

August 1989
Order Number: 231051-005

PIN DESCRIPTIONS

Symbol	Pin No.	Type	Name and Function
$\overline{S0}$ $\overline{S1}$ $\overline{S2}$	27 26 25	I	**Status Input Pins** $\overline{S0}$–$\overline{S2}$ correspond to the status pins of the CPU. The 82188 uses the status lines to detect and identify the processor bus cycles. The 82188 decodes $\overline{S0}$–$\overline{S2}$ to generate the command and control signals. $\overline{S0}$–$\overline{S2}$ are also used to insert 3 wait states into the SRO line during the first 256 80186 bus cycles after RESET. A HIGH input on all three lines indicates that no bus activity is taking place. The status input lines contain weak internal pull-up devices.

$\overline{S2}$	$\overline{S1}$	$\overline{S0}$	Bus Cycle Initiated
0	0	0	interrupt acknowledge
0	0	1	read I/O
0	1	0	write I/O
0	1	1	halt
1	0	0	instruction fetch
1	0	1	read data from memory
1	1	0	write data to memory
1	1	1	passive (no bus cycle)

CLK	15	I	**CLOCK** CLK is the clock signal generated by the CPU or clock generator device. CLK edges establish when signals are sampled and generated.
RESET	5	I	**RESET** RESET is a level triggered signal that corresponds to the system reset signal. The signal initializes an internal bus cycle counter, thus enabling the 82188 to insert internally generated wait states into the SRO signal during system initialization. The 82188 mode is also determined during RESET. $\overline{RD}$, $\overline{WR}$, and $\overline{DEN}$ are driven HIGH during RESET regardless of $\overline{AEN}$. RESET is active HIGH.
$\overline{AEN}$	19	I	**Address Enable** This signal enables the system command lines when active. If $\overline{AEN}$ is inactive (HIGH), $\overline{RD}$, $\overline{WR}$, and $\overline{DEN}$ will be tri-stated and ALE will be driven LOW (DT/$\overline{R}$ will not be effected). $\overline{AEN}$ is an asynchronous signal and is active LOW.
ALE	24	O	**Address Latch Enable** This signal is used to strobe an address into address latches. ALE is active HIGH and latch should occur on the HIGH to LOW transition. ALE is intended for use with transparent D-type latches.
$\overline{DEN}$	21	O	**Data Enable** This signal is used to enable data transceivers located on either the local or system data bus. The signal is active LOW. $\overline{DEN}$ is tri-stated when $\overline{AEN}$ is inactive.
DT/$\overline{R}$	20	O	**Data TRANSMIT/RECEIVE** This signal establishes the direction of data flow through the data transceivers. A HIGH on this line indicates TRANSMIT (write to I/O or memory) and a LOW indicates RECEIVE (Read from I/O or memory).

PIN DESCRIPTIONS (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{RD}$	23	O	**READ** This signal instructs an I/O or memory device to drive its data onto the data bus. The $\overline{RD}$ signal is similiar to the $\overline{RD}$ signal of the 80186(80188) in Non-Queue-Status Mode. $\overline{RD}$ is active LOW and is tri-stated when $\overline{AEN}$ is inactive.
$\overline{WR}$	22	O	**WRITE** This signal instructs an I/O or memory device to record the data presented on the data bus. The $\overline{WR}$ signal is similiar to the $\overline{WR}$ signal of the 80186(80188) in Non-Queue-Status Mode. $\overline{WR}$ is active LOW and is tri-stated when $\overline{AEN}$ is inactive.
HOLD	7	O	**HOLD** The HOLD signal is used to request bus control from the 80186 or 80188. The request can come from either the 8087 ($\overline{RQ}/\overline{GT}O$) or from the third processor (SYSHOLD). The signal is active HIGH.
HLDA	6	I	**HOLD Acknowledge** 80186 MODE–This line serves to translate the HLDA output of the 80186(80188) to the appropriate signal of the device requesting the bus. HLDA going active (HIGH) indicates that the 80186 has relinquished the bus. If the requesting device is the 8087, HLDA will be translated into the grant pulse of the $\overline{RQ}/\overline{GT}O$ line. If the requesting device is the optional third processor, HLDA will be routed into the SYSHLDA line. This pin also determines the mode in which the 82188 will operate. If this line is HIGH during the falling edge of RESET, the 82188 will enter the 8086 mode. If LOW, the 82188 will enter the 80186 mode. For 8086 mode, this pin should be strapped to V_{CC}.
$\overline{RQ}/\overline{GT}O$	8	I/O	**Request/Grant O** $\overline{RQ}/\overline{GT}O$ is connected to $\overline{RQ}/\overline{GT}O$ of the 8087 Numeric Coprocessor. When initiated by the 8087, $\overline{RQ}/\overline{GT}O$ will be translated to HOLD-HLDA to acquire the bus from the 80186(80188). This line is bidirectional, and is active LOW. $\overline{RQ}/\overline{GT}O$ has a weak internal pull-up device to prevent erroneous request/grant signals.
$\overline{RQ}/\overline{GT}1$	11	I/O	**Request/Grant 1** 80186 Mode–In 80186 Mode, $\overline{RQ}/\overline{GT}1$ allows a third processor to take control of the local bus when the 8087 has bus control. For a HOLD-HLDA type third processor, the 82188's $\overline{RQ}/\overline{GT}1$ line should be connected to the $\overline{RQ}/\overline{GT}1$ line of the 8087. 8086 MODE–In 8086 Mode, $\overline{RQ}/\overline{GT}1$ is connected to either $\overline{RQ}/\overline{GT}O$ or $\overline{RQ}/\overline{GT}1$ of the 8086. $\overline{RQ}/\overline{GT}1$ will start its request/grant sequence when the SYSHOLD line goes active. In 8086 Mode, $\overline{RQ}/\overline{GT}1$ is used to gain bus control from the 8086 or 8088. $\overline{RQ}/\overline{GT}1$ is a bidirectional line and is active LOW. This line has a weak internal pull-up device to prevent erroneous request/grant signals.

PIN DESCRIPTIONS (Continued)

Symbol	Pin No.	Type	Name and Function
SYSHOLD	9	I	**System Hold** 80186 MODE–SYSHOLD serves as a hold input for an optional third processor in an 80186(80188)-8087 system. If the 80186(80188) has bus control, SYSHOLD will be routed to HOLD to gain control of the bus. If the 8087 has bus control, SYSHOLD will be translated to $\overline{RQ}/\overline{GT}1$ to gain control of the bus. 8086 MODE–SYSHOLD serves as a hold input for a coprocessor in an 8086 or 8088 system. SYSHOLD is translated to $\overline{RQ}/\overline{GT}1$ of the 82188 to allow the coprocessor to take control of the bus. SYSHOLD may be an asynchronous signal.
SYSHLDA	10	O	**System Hold Acknowledge** SYSHLDA serves as a hold acknowledge line to the processor or coprocessor connected to it. The device connected to the SYSHOLD-SYSHLDA lines is allowed the bus when SYSHLDA goes active (HIGH).
SRDY	17	I	**Synchronous Ready** The SRDY input serves the same function as SRDY of the 80186(80188). The 82188 combines SRDY with ARDY to form a synchronized ready output signal (SRO). SRDY must be synchronized external to the 82188 and is active HIGH. If tied to V_{CC}, SRO will remain active (HIGH) after the first 256 80186 cycles following RESET. If only ARDY is to be used, SRDY should be tied LOW.
ARDY	18	I	**Asynchronous Ready** The ARDY input serves the same function as ARDY of the 80186(80188). ARDY may be an asynchronous input, and is active HIGH. Only the rising edge of ARDY is synchronized by the 82188. The falling edge must be synchronized external to the 82188. If connected to V_{CC}, SRO will remain active (HIGH) after the first 256 80186 bus cycles following RESET. If only SRDY is to be used, ARDY should be connected LOW.
SRO	16	O	**Synchronous READY Output** SRO provides a synchronized READY signal which may be interfaced directly with the SRDY of the 80186(80188) and READY of the 8087. The SRO signal is an accumulation of the synchronized ARDY signal, the SRDY signal, and the internally generated wait state signal.
QS0I QS1I	1 2	I	**Queue-Status Inputs** QS0I, QS1I are connected to the Queue-Status lines of the 80186(80188) to allow synchronization of the queue-status signals to 8087 timing requirements.
QS0O QS1O	3 4	O	**Queue-Status Outputs** QS0O, QS1O are connected to the queue-status pins of the 8087. The signals produced meet 8087 Queue-Status input requirements.

PIN DESCRIPTIONS (Continued)

Symbol	Pin No.	Type	Name and Function
$\overline{CSIN}$	13	I	**Chip-Select Input** $\overline{CSIN}$ is connected to one of the chip-select lines of the 80186(80188). $\overline{CSIN}$ informs the 82188 that a bank select is taking place. The 82188 routes this signal to the chip-select output ($\overline{CSOUT}$). $\overline{CSIN}$ is active LOW. This line is not used when memory and I/O device addresses are decoded external to the 80186(80188).
$\overline{CSOUT}$	12	O	**Chip-Select Output** This signal is used as a chip-select line for a bank of memory devices. It is active when $\overline{CSIN}$ is active or when the 8087 has bus control. $\overline{CSOUT}$ is active LOW.

1

FUNCTIONAL DESCRIPTION

BUS CONTROLLER

The 82188 Integrated Bus Controller (IBC) generates system control and command signals. The signals generated are determined by the Status Decoding Logic. The bus controller logic interprets status lines $\overline{S0}$–$\overline{S2}$ to determine what type of bus cycle is taking place. The appropriate signals are then generated by the Command and Control Signal Generators.

The Address Enable ($\overline{AEN}$) line allows the command and control signals to be disabled. When $\overline{AEN}$ is inactive (HIGH), the command signals and $\overline{DEN}$ will be tri-stated, and ALE will be held low (DT/$\overline{R}$ will be uneffected). $\overline{AEN}$ inactive will allow other systems to take control of the bus. Control and command signals respond to a change in the $\overline{AEN}$ signal within 40 ns.

The command signals consist of $\overline{RD}$ and $\overline{WR}$. The 82188's $\overline{RD}$ and $\overline{WR}$ signals are similiar to $\overline{RD}$ and $\overline{WR}$ of the 80186(80188) in the non-Queue-Status Mode. These command signals do not differentiate between memory and I/O devices. $\overline{RD}$ and $\overline{WR}$ can be conditioned by $\overline{S2}$ of the 80186(80188) to obtain separate signals for I/O and memory devices. $\overline{RD}$ is asserted during INTA cycles, unlike $\overline{RD}$ on the 80186(80188).

The control commands consist of Data Enable ($\overline{DEN}$), Data Transmit/Receive (DT/$\overline{R}$), and Address Latch Enable (ALE). The control commands are similiar to those generated by the 80186(80188). $\overline{DEN}$ determines when the external bus should be enabled onto the local bus. DT/$\overline{R}$ determines the direction of the data transfer, and ALE determines when the address should be strobed into the latches (used for demultiplexing the address bus). DT/$\overline{R}$ does not go to an inactive (high) state at the end of bus cycles, unlike DT/$\overline{R}$ on the 80186(80188).

MODE SELECT

The 82188 Integrated Bus Controller (IBC) is configurable. The device has two modes: 80186 Mode and 8086 Mode. Selecting the mode of the device configures the Bus Arbitration Logic (see BUS ARBITRATION section for details). In 80186 Mode, the 82188 IBC may be used as a bus controller/interface device for an 80186(80188), 8087, and optional third processor system. In 8086 Mode, the 82188 IBC may be used as an interface device allowing a maximum mode 8086(8088) to interface with a coprocessor that uses a HOLD-HLDA bus exchange protocol.

The mode of the 82188 is determined during RESET. If the HLDA line is LOW at the falling edge of RESET (as in the case when tied to the HLDA line of the 80186 or 80188), the 82188 will enter into 80186 Mode. If the HLDA line is HIGH at the falling edge of RESET, the 82188 will enter 8086 Mode. In 8086 Mode, only the Bus Arbitration Logic is used. The eight pins used in 8086 Mode are: SYSHOLD, SYSHLDA, HLDA, CLK, RESET, $\overline{RQ}/\overline{GT1}$, V_{CC}, and V_{SS}. The other pins may be left unconnected.

BUS ARBITRATION

The Bus Exchange Logic interfaces up to three sets of bus exchange signals:

- HOLD-HLDA
- SYSHOLD-SYSHLDA
- $\overline{RQ}/\overline{GT0}$ ($\overline{RQ}/\overline{GT1}$)

This logic executes translating, routing, and arbitrating functions. The logic translates HOLD-HLDA signals to $\overline{RQ}/\overline{GT}$ signals and $\overline{RQ}/\overline{GT}$ signals to HOLD-HLDA signals. The logic also determines which set of bus exchange signals are to be interfaced. The mode of the 82188 and the priority of the devices requesting the bus determine the routing of the bus exchange signals.

80186 MODE

In 80186 Mode, a system may have three potential bus masters: the 80186 or 80188 CPU, the 8087 Numerics Coprocessor, and a third processor (such as the 82586 LAN or 82730 Text Coprocessor). The third processor may have either a HOLD-HLDA or $\overline{RQ}/\overline{GT}$ bus exchange protocol. The possible bus exchange signal connections and paths for 80186 Mode are shown in Figures 3 & 4 and Tables 1 & 2, respectively. If no HOLD-HLDA type third processor is used, SYSHOLD should be tied LOW to prevent an erroneous SYSHOLD signal. In 80186 mode, the bus priorities are:

Highest Priority.....Third Processor
Second Highest Priority.....8087
Default Priority.....80186

— THREE-PROCESSOR SYSTEM OPERATION (HOLD-HLDA TYPE THIRD PROCESSOR)

In the configuration shown in Figure 3, the third processor requests the bus by sending SYSHOLD HIGH. The 82188 will route (and translate if necessary) the request to the current bus master. This includes routing the request to HOLD if the 80186(80188) is the current bus master or routing and translating the request to $\overline{RQ}/\overline{GT}1$ if the 8087 is in control of the bus. The third processor's request is not passed through the 8087 if the 80186 is the bus master (see Table 1).

The 8087 requests the bus using $\overline{RQ}/\overline{GT}0$. The request pulse from the 8087 will be translated and routed to HOLD if the 80186 is the bus master. If the third processor has control of the bus, the grant pulse to the 8087 will be delayed until the third processor relinquishes the bus (sending SYSHOLD LOW). In this case, HOLD will remain HIGH during the third processor-to-8087 bus control transfer. The 80186 will not be granted the bus until both coprocessors have released it.

Table 1. Bus Exchange Paths (80186 Mode) (HOLD-HLDA Type 3rd Proc)

Requesting Device	Current Bus Master		
	80186	8087	3rd Proc
80186	n/a	n/a	n/a
8087	$\overline{RQ}/\overline{GT}0 \longleftrightarrow \frac{HOLD}{HLDA}$	n/a	n/a
3rd Proc	$\frac{SYSHOLD}{SYSHLDA} \longleftrightarrow \frac{HOLD}{HLDA}$	$\frac{SYSHOLD}{SYSHLDA} \longleftrightarrow \overline{RQ}/\overline{GT}1$	n/a

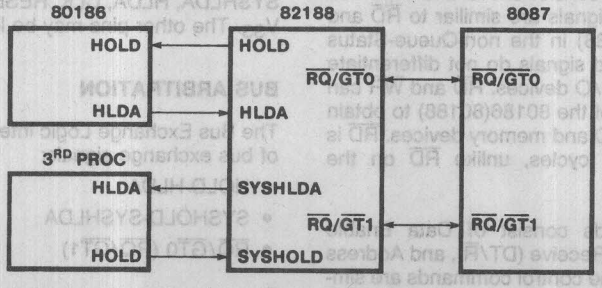


Figure 3.
Bus Exchange Signal Connections (80186 Mode) for a Three Local Processor System (HOLD-HLDA Type 3rd Proc)

Table 2. Bus Exchange Paths (80186 Mode) ($\overline{RQ}/\overline{GT}$ Type 3rd Proc)

Requesting Device	Current Bus Master		
	80186	8087	3rd Proc
80186	n/a	n/a	n/a
8087	$\overline{RQ}/\overline{GT}0 \longleftrightarrow$ HOLD / HLDA	n/a	n/a
3rd Proc	$\overline{RQ}/\overline{GT}1 \longleftrightarrow \overline{RQ}/\overline{GT}0 \longleftrightarrow$ HOLD / HLDA	$\overline{RQ}/\overline{GT}1$	n/a

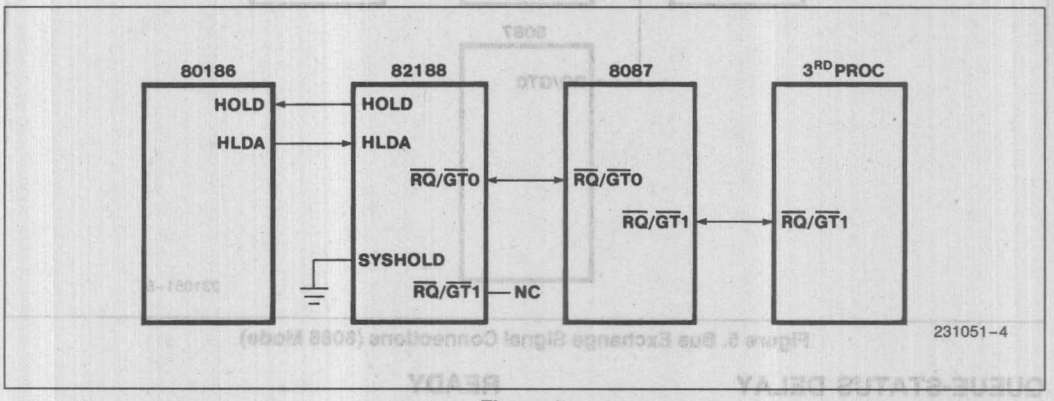


Figure 4.
Bus Exchange Signal Connections (80186 Mode) for a Three Local Processor System ($\overline{RQ}/\overline{GT}$ Type 3rd Proc)

When the bus is requested from the 80186(80188), a bus priority decision is made. This decision is made when the HLDA line goes active. Upon receipt of the HLDA signal, the highest-priority requesting device will be acknowledged the bus. For example, if the 8087 initially requested the bus, the bus will be granted to the third processor if SYSHOLD became active before HLDA was received by the 82188. In this case, the grant pulse to the 8087 will be delayed until the third processor relinquishes the bus.

— THREE-PROCESSOR SYSTEM OPERATION ($\overline{RQ}/\overline{GT}$ TYPE THIRD PROCESSOR)

In the configuration shown in Figure 4, the third processor requests the bus by initiating a request/grant sequence with the 8087's $\overline{RQ}/\overline{GT}1$ line. The 8087 will grant the bus if it is the current bus master or will pass the request on if the 80186 is the current bus master (see Table 2). In this configuration, the 82188's Bus Arbitration Logic translates $\overline{RQ}/\overline{GT}0$ to HOLD-HLDA. The 8087 provides the bus arbitration in this configuration.

8086 MODE

The 8086 Mode allows an 8086, 8088 system to contain both $\overline{RQ}/\overline{GT}$ and HOLD-HLDA type coprocessors simultaneously. In 8086 Mode, two possible bus masters may be interfaced by the 82188; an 8086 or 8088 CPU and a coprocessor which uses a HOLD-HLDA bus exchange protocol (typically an 82586 LAN Coprocessor or an 82730 Text Coprocessor). The bus exchange signal connections for 8086 Mode are shown in Figure 5. Bus arbitration signals used in the 8086 Mode are:

- $\overline{RQ}/\overline{GT}1$
- SYSHOLD
- SYSHLDA

In 8086 Mode, no arbitration is necessary since only two devices are interfaced. The coprocessor has bus priority over the 8086(8088). SYSHOLD-SYSHLDA are routed and translated directly to $\overline{RQ}/\overline{GT}1$. $\overline{RQ}/\overline{GT}1$ of the 82188 may be tied to either $\overline{RQ}/\overline{GT}0$ or $\overline{RQ}/\overline{GT}1$ of the 8086(8088).

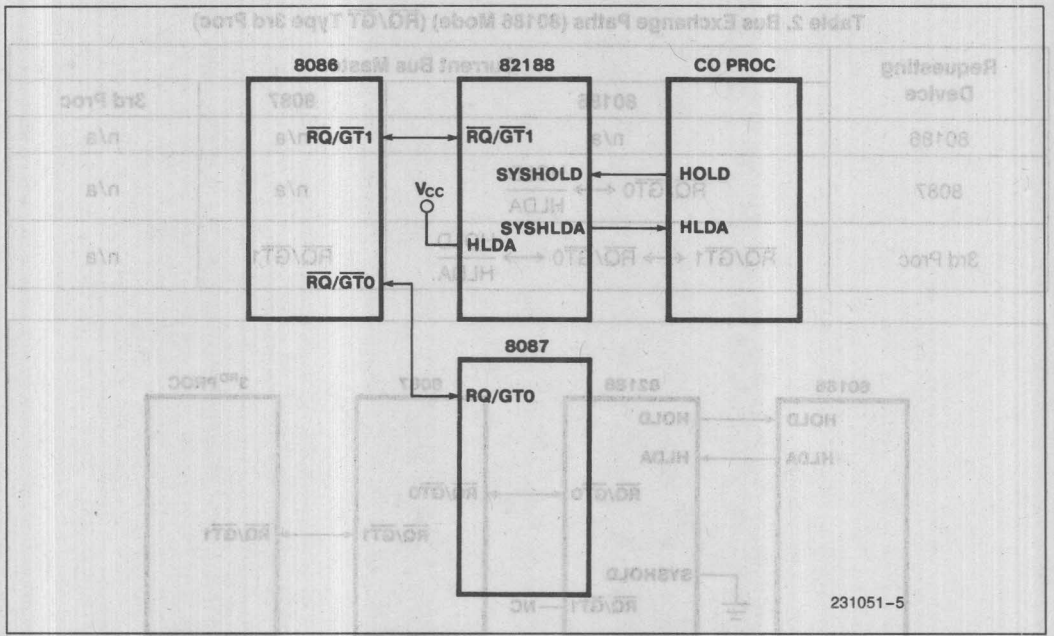


Figure 5. Bus Exchange Signal Connections (8086 Mode)

QUEUE-STATUS DELAY

The Queue-Status Delay logic is used to delay the queue-status signals from the 80186(80188) to meet 8087 queue-status timing requirements. QS0I, QS1I correspond to the queue-status lines of the 80186(80188). The 82188 delays these signals by one clock phase. The delayed signals are interfaced to the 8087 queue-status lines by QS0O, QS1O.

CHIP-SELECT

The Chip-Select Logic allows the utilization of the chip select circuitry of the 80186(80188). Normally, this circuitry could not be used in an 80186(80188)-8087 system since the 8087 contains no chip select circuitry. The Chip-Select Logic contains two external connections: Chip-Select Input ($\overline{CSIN}$) and Chip-Select Output ($\overline{CSOUT}$). $\overline{CSOUT}$ is active when either $\overline{CSIN}$ is active or when the 8087 has control of the bus.

By using $\overline{CSOUT}$ to select memory containing data structures, no external decoding is necessary. The 80186 may gain access to this memory bank through the $\overline{CSIN}$ line while the 8087 will automatically obtain access when it becomes the bus master. Note that this configuration limits the amount of memory accessible by the 8087 to the physical memory bank selected by $\overline{CSOUT}$. Systems where the 8087 must access the full 1 Megabyte address space must use an external decoding scheme.

READY

The Ready logic allows two types of Ready signals: a Synchronous Ready Signal (SRDY) and an Asynchronous Ready Signal (ARDY). These signals are similiar to SRDY and ARDY of the 80186. Wait states will be inserted when both SRDY and ARDY are LOW. Inserting wait states allows slower memory and I/O devices to be interfaced to the 80186(80188)-8087 system.

ARDY's LOW-to-HIGH transition is synchronized to the CPU clock by the 82188. The 82188 samples ARDY at the beginning of T2, T3 and Tw until sampled HIGH. Note that ARDY of the 82188 is sampled one phase earlier than ARDY of the 80186. ARDY's falling edge must be synchronous to the CPU clock. ARDY allows an easy interface with devices that emit an asynchronous ready signal.

The SRDY signal allows direct interface to devices that emit a synchronized ready signal. SRDY must be synchronized to the CPU clock for both of its transitions. SRDY is sampled in the middle of T2, T3 and in the middle of each Tw. An 82188-80186(80188)'s SRDY setup time is 30 ns longer than the 80186(80188)'s SRDY setup time. SRDY eliminates the half-clock cycle penalty necessary for ARDY to be internally sychronized.

The sychronized ready output (SRO) is the accumulation of SRDY, ARDY, and the internal wait-state

generator. SRO should be connected to SRDY of the 80186(80188) (with 80186(80188)'s ARDY tied LOW), and READY of the 8087.

SRDY	ARDY	SRO
0	0	0
1	X	1
X	1	1

The internal wait state generator allows for synchronization between the 80186(80188) and 8087 in 80186 mode. Upon RESET, the 82188 automatically inserts 3 wait-states per 80186(80188) bus cycle, overlapped with any externally produced wait-states created by ARDY and SRDY.

Since the 8087 has no provision for internal wait-state generation, only externally created wait states will be effective. The 82188, upon RESET, will inject 3 wait states for each of the first 256 80186(80188) bus cycles onto the SRO line. This will allow the 8087 to match the 80186(80188)'s timing.

The internally-generated wait states are overlapped with those produced by the SRDY and ARDY lines. Overlapping the injected wait states insures a minimum of three wait states for the first 256 80186(80188) bus cycles after RESET. Systems with a greater number of wait states will not be affected. Internal wait state generation by the 82188 will stop on the 256th 80186(80188) bus cycle after RESET. To maintain sychronization between the 80186(80188) and 8087, the following conditions are necessary:

- The 80186(80188)'s control block must be mapped in I/O space before it is written to or read from.
- All memory chip-select lines must be set to 0 WAIT STATES, EXTERNAL READY ALSO USED within the first 256 80186(80188) bus cycles after RESET.

An equivalent READY logic diagram is shown in Figure 6.

SYSTEM CONSIDERATIONS

In any 82188 configuration, clock compatibility must be considered. Depending on the device, a 50% or a 33% duty-cycle clock is needed. For example, the 80186 and 80188 (as well as the 82188, 82586, and 82730) requires a 50% duty-cycle clock. The 8086, 8088 and their 'kit' devices' (8087, 8089, 82C88, and 8289) clock requirements, on the other hand, require a 33% duty-cycle clock signal. The system designer must make sure clock requirements of all the devices in the system are met.

Figure 7 demonstrates the usage of the 82188 in 80186 Mode where it is used to interface an 8087 into an 80186 system. In this case, the clock requirements of the 8087 are met by specifying the 10 MHz (8087-1) device, but clocking the system at a maximum rate of 8 MHz.

Status bit six (S6) from the main processor (8086, 8088, 80186, or 80188) is used by the 8087 to track the instruction flow. S6 is multiplexed with address bit 19 (A19). If the third processor generates only 16 bits of address, S6 is not generated. A19/S6 must be driven high by external circuitry during the status portion of bus cycles controlled by the third processor.

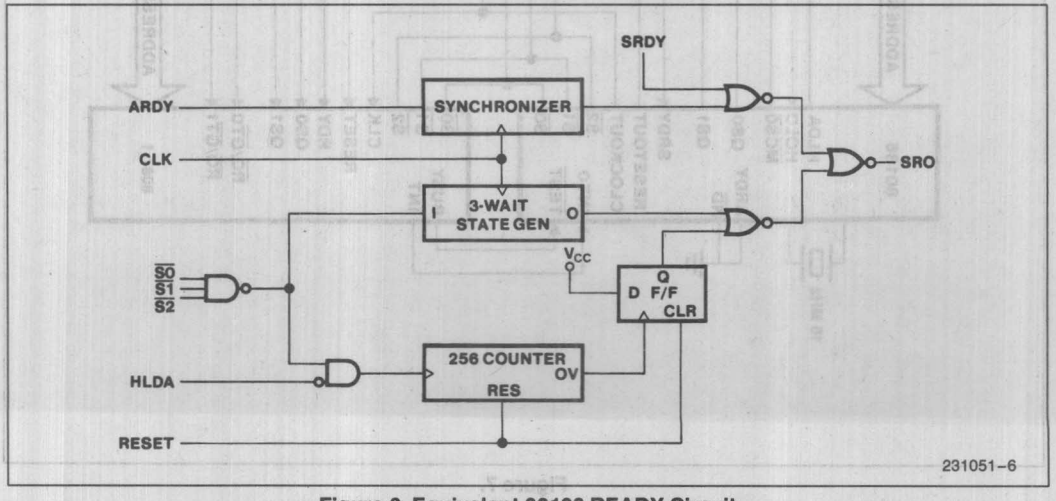


Figure 6. Equivalent 82188 READY Circuit

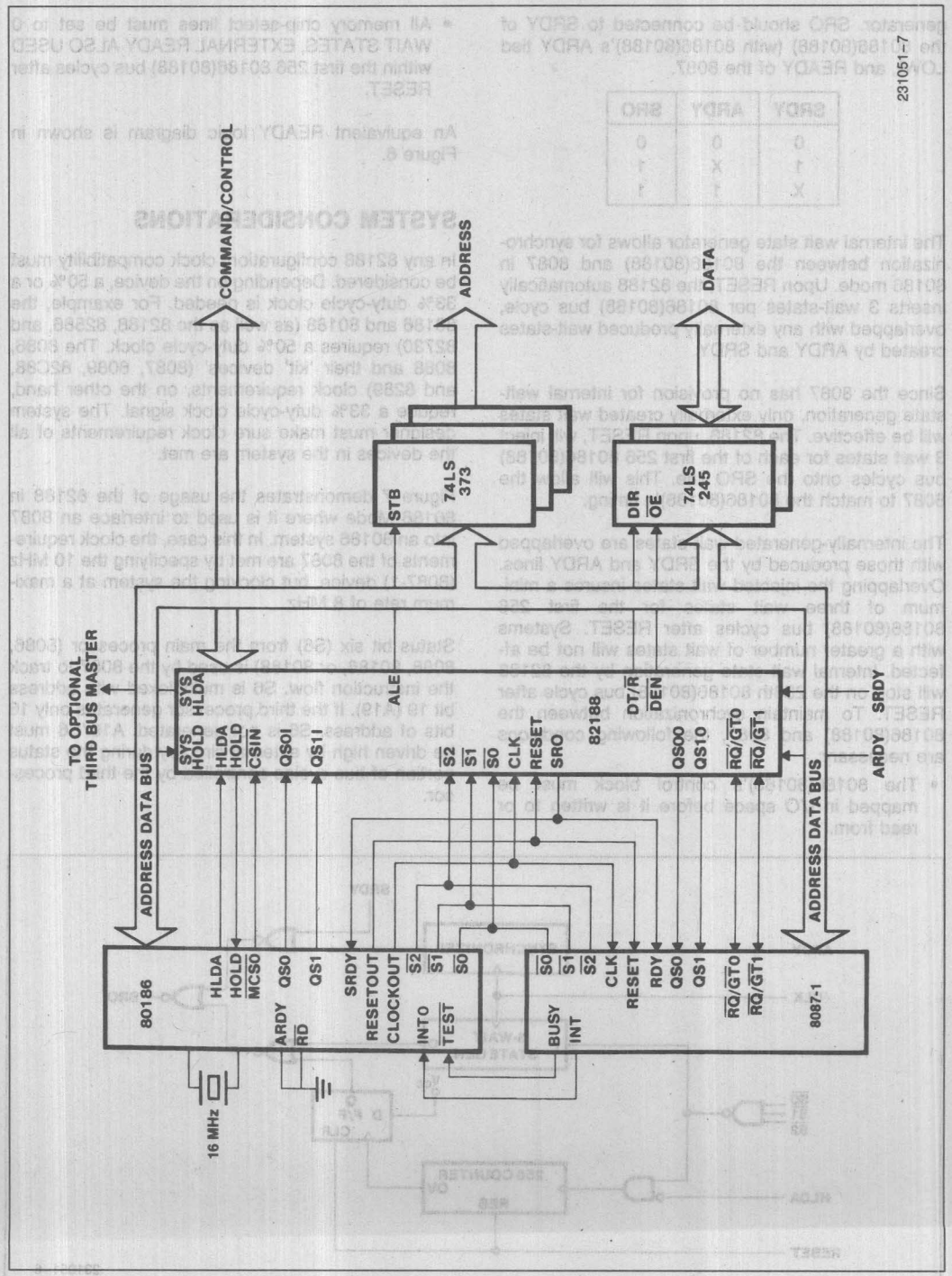


Figure 7.
80186/8087-1 System Using the 82188 in 80186 Mode

ABSOLUTE MAXIMUM RATINGS *

Temperature Under Bias .....0°C to 70°C
Storage Temperature.....−65°C to 150°C
Case Temperature .....0°C to +85°C
Voltage on any Pin with Respect to GND .....−1.0V to 7.0V
Power Dissipation .....0.7 Watts

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

DC CHARACTERISTICS

(V_{CC} = 5V ± 10%, T_A = 0°C to 70°C, T_{CASE} = 0°C to +85°C)

Symbol	Parameter	Min	Max	Units	Test Cond.
V_{IL}	Input Low Voltage	−0.5	+0.8	volts	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.5	volts	
V_{OL}	Output Low Voltage		0.45	volts	I_{OL} = 2 mA
V_{OH}	Output High Voltage	2.4		volts	I_{OH} = −400 µA
I_{CC}	Power Supply Current		100	mA	T_A = 25°C
I_{LI}	Input Leakage Current		±10	µA	$0V < V_{IN} < V_{CC}$
I_{LO}	Output Leakage Current		±10	µA	$0.45 < V_{OUT} < V_{CC}$
V_{CLI}	CLK Input Low Voltage	−0.5	+0.6	volts	
V_{CHI}	CLK Input High Voltage	3.9	V_{CC} +1.0	volts	
C_{IN}	Input Capacitance		10	pF	
C_{IO}	I/O Capacitance		20	pF	

AC CHARACTERISTICS

(V_{CC} = 5V ± 10%, T_A = 0°C to 70°C, T_{CASE} = 0°C to +85°C)

TIMING REQUIREMENTS

Symbol	Parameter	Min	Max	Units	Notes
TCLCL	Clock Period	125	500	ns	
TCLCH	Clock LOW Time	½TCLCL-7.5		ns	
TCHCL	Clock HIGH Time	½TCLCL-7.5		ns	
TARYHCL	ARDY Active Setup Time	20		ns	
TCHARYL	ARDY Hold Time	15		ns	8
TARYLCH	ARDY Inactive Setup Time	35		ns	
TSRYHCL	SRDY Input Setup Time	65,50		ns	1
TSVCH	STATUS Active Setup Time	55		ns	
TSXCL	STATUS Inactive Setup Time	50		ns	
TQIVCL	QS0I, QS1I Setup Time	15		ns	
THAVGV	HLDA Setup Time	50		ns	
TSHVCL	SYSHOLD Asynchronous Setup Time	25		ns	
TGVCH	$\overline{RQ}/GT$ Input Setup Time	0		ns	6

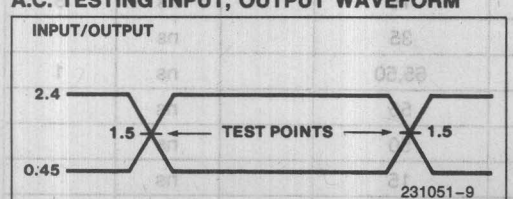
TIMING RESPONSES

Symbol	Parameter	Min	Max	Units	Notes
TSVLH	STATUS Valid to ALE Delay		30	ns	4
TCHLL	ALE Inactive Delay		30	ns	
TCLML	$\overline{RD}$, $\overline{WR}$ Active Delay	10	70	ns	
TCLMH	$\overline{RD}$, $\overline{WR}$ Inactive Delay	10	55	ns	
TSVDTV	STATUS to DT/$\overline{R}$ Delay		30	ns	3
TCLDTV	DT/$\overline{R}$ Active Delay		55	ns	3
TCHDNV	$\overline{DEN}$ Active Delay	10	55	ns	
TCHDNX	$\overline{DEN}$ Inactive Delay	10	55	ns	
TCLQOV	QS0O, QS1O Delay	5	50	ns	
TCHHV	HOLD Delay		50	ns	2,6
TCLSAV	SYSHLDA Delay		50	ns	6
TCLGV	$\overline{RQ}$/$\overline{GT}$ Output Delay		40	ns	6
TGVHV	$\overline{RQ}$/$\overline{GT}$0 To HOLD Delay		50	ns	2,6
TCLLH	ALE Active Delay		30	ns	4
TAELCV	Command Enable Delay		40	ns	
TAEHCX	Command Disable Delay		40	ns	
TCHRO	SRO Output Delay	5	30	ns	5,6
TSRYHRO	SRDY To SRO Delay		30	ns	5
TCSICSO	$\overline{CSIN}$ To $\overline{CSOUT}$ Delay		30	ns	
TCLCSOV	CLK Low to $\overline{CSOUT}$ Delay	10		ns	
TCLCSOH	CLK Low to $\overline{CSOUT}$ Inactive Delay	10		ns	

NOTES (applicable to both spec listing and timing diagrams):

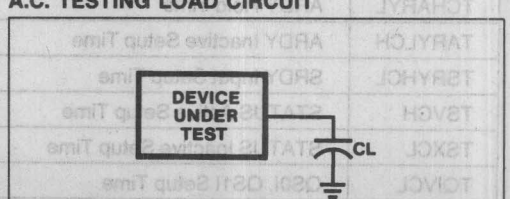
1. TSRYHOL = (80186's) TSRYCL + 30 ns=65 ns for 6 MHz operation and 50 ns for 8 MHz operation.
2. Timing not tested.
3. DT/$\overline{R}$ will be asserted to the latest of TSVDTV & TCLDTV.
4. ALE will be asserted to the latest of TSVLH & TCLLH.
5. SRO will be asserted to the latest of TCHRO & TSRYHRO.
6. CL = 20–100 pF
7. Address/Data bus shown for reference only.
8. The falling edge of ARDY must be synchronized to CLK.

A.C. TESTING INPUT, OUTPUT WAVEFORM

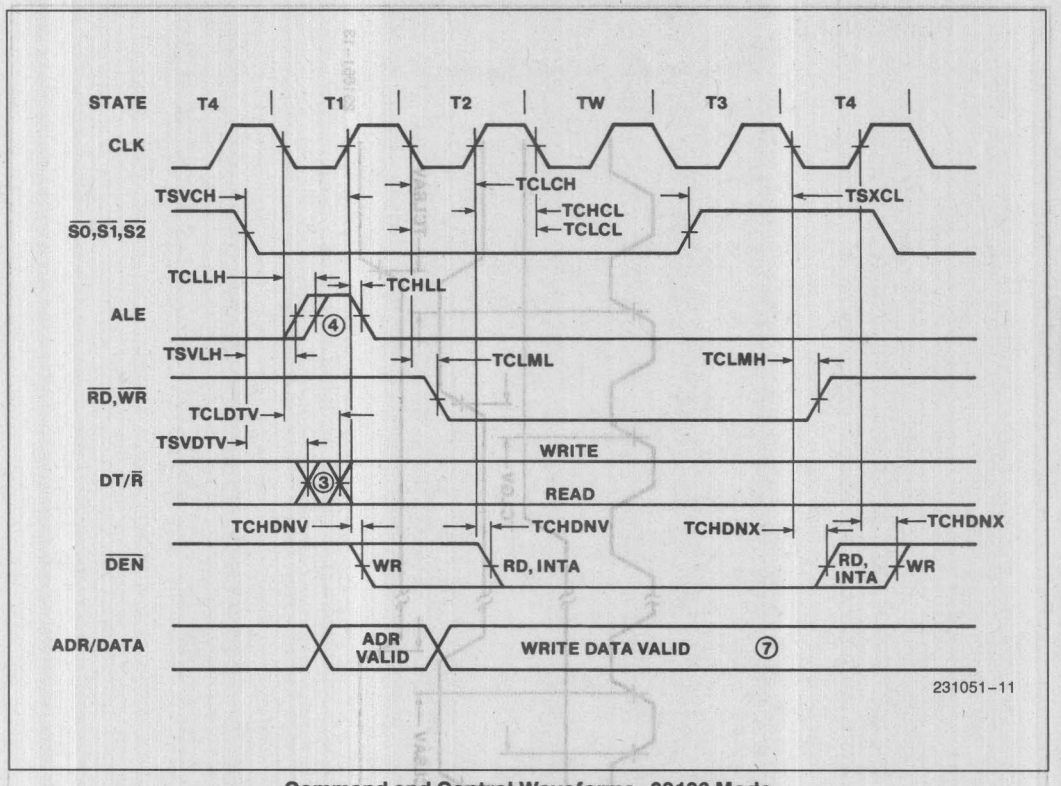


A.C. Testing: Inputs are driven at 2.4V for a Logic '1' and 0.45V for a Logic '0'.

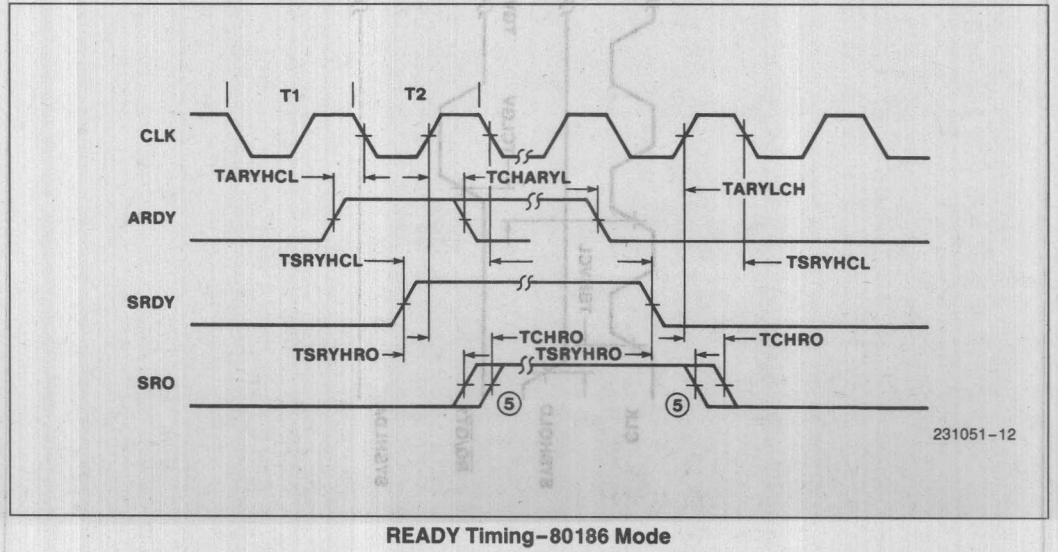
A.C. TESTING LOAD CIRCUIT



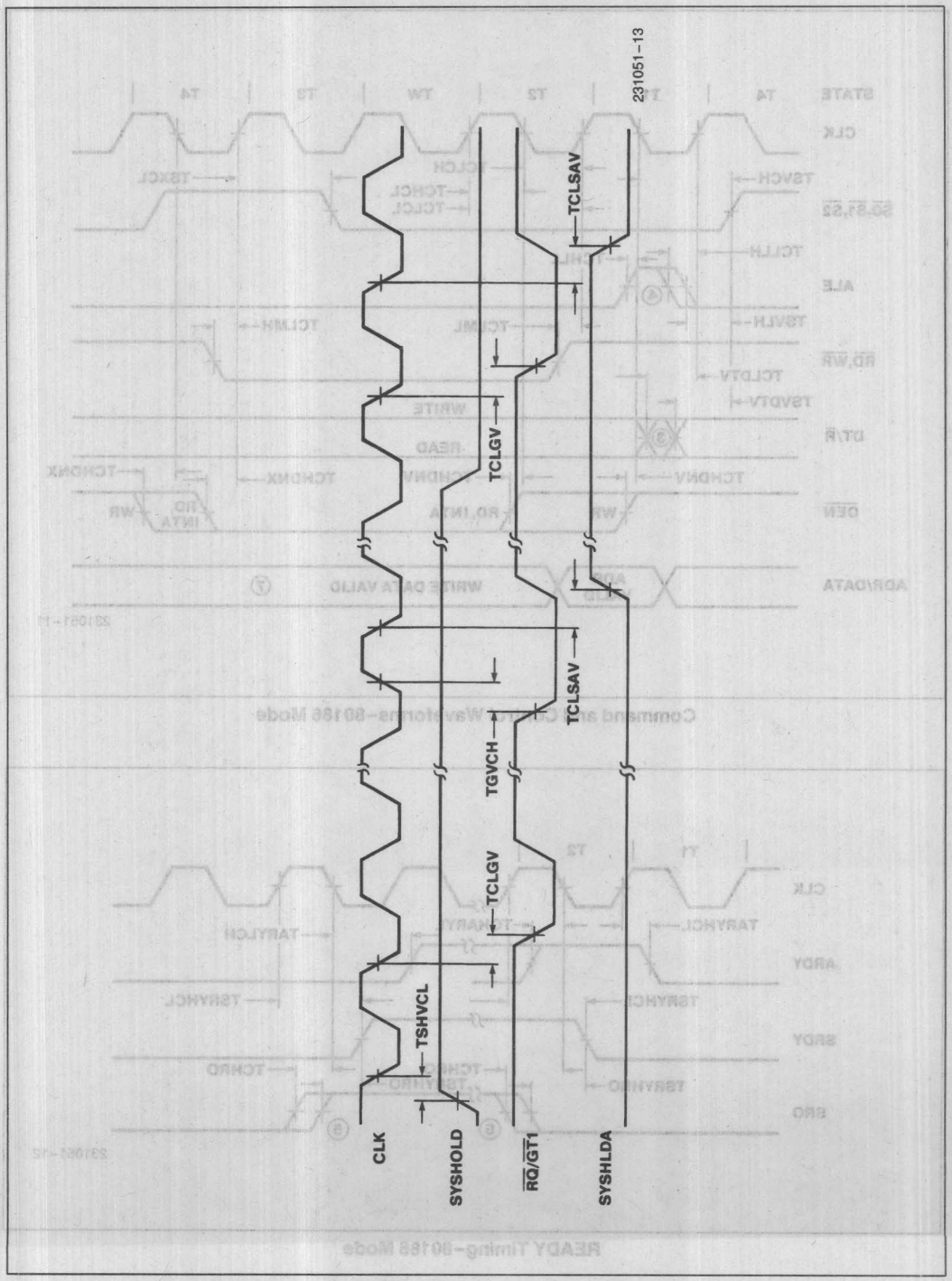
C_L includes Jig Capacitance
C_L = 20–200 pF unless otherwise noted



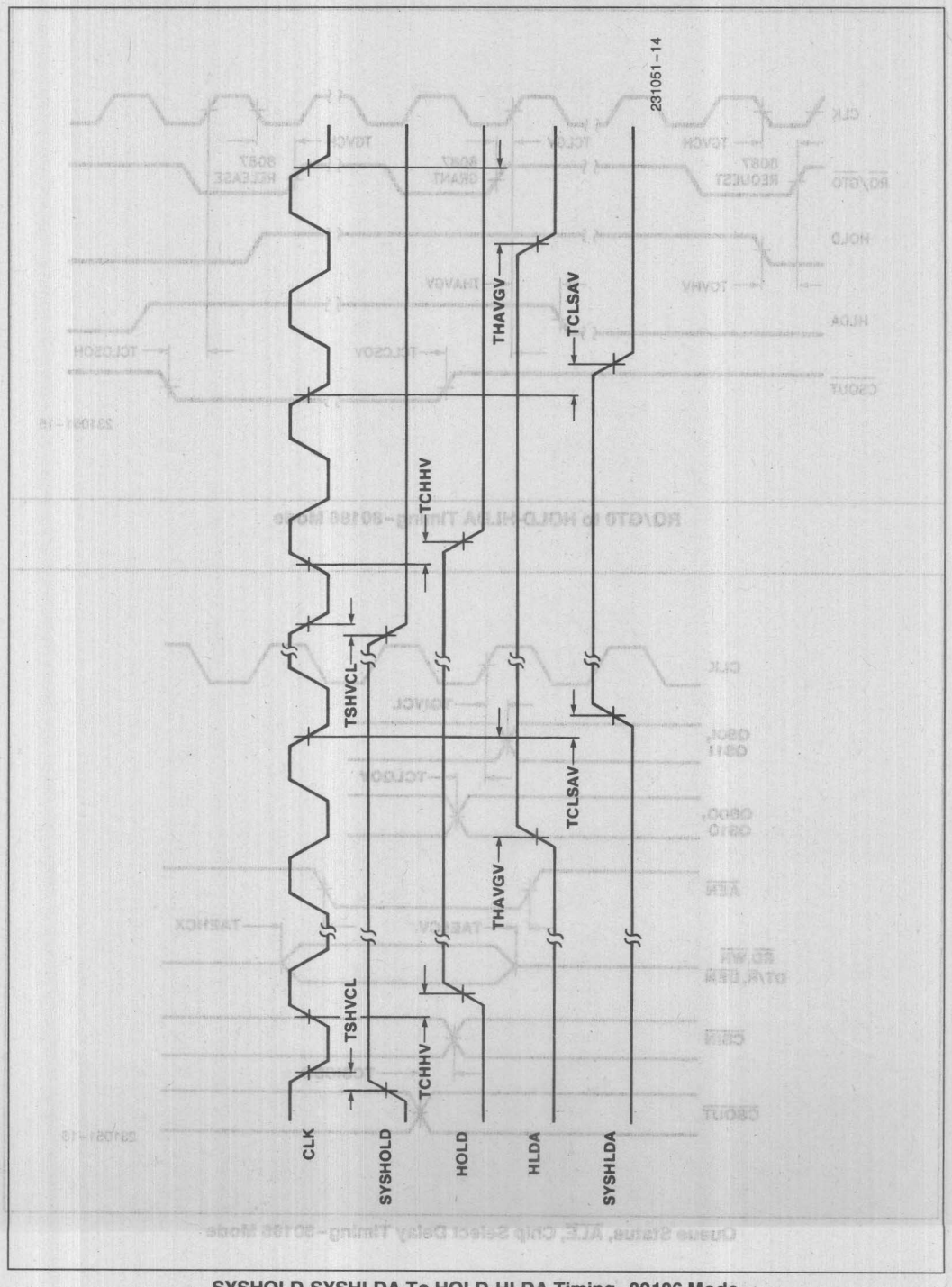
Command and Control Waveforms–80186 Mode



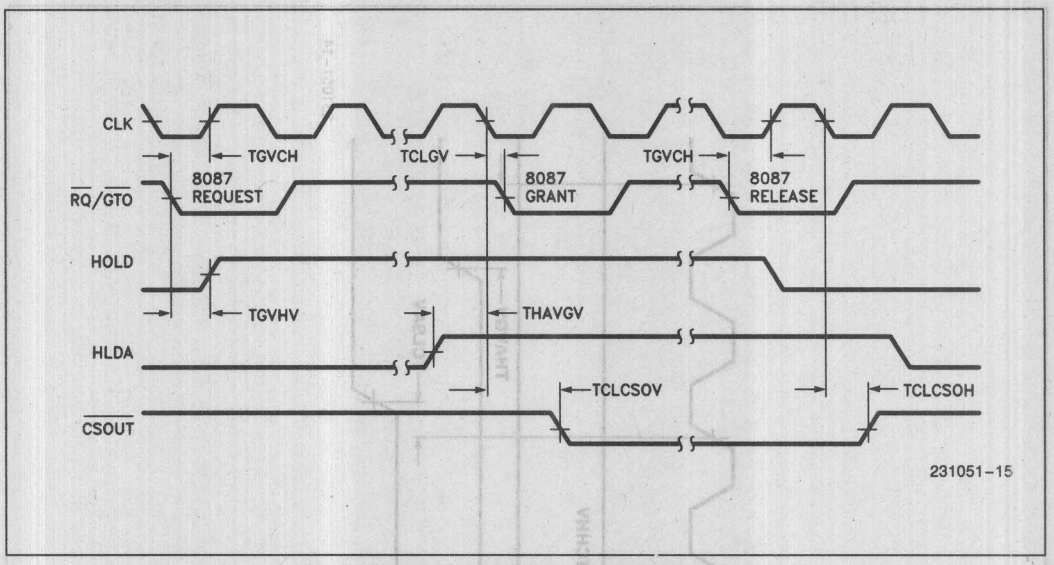
READY Timing–80186 Mode



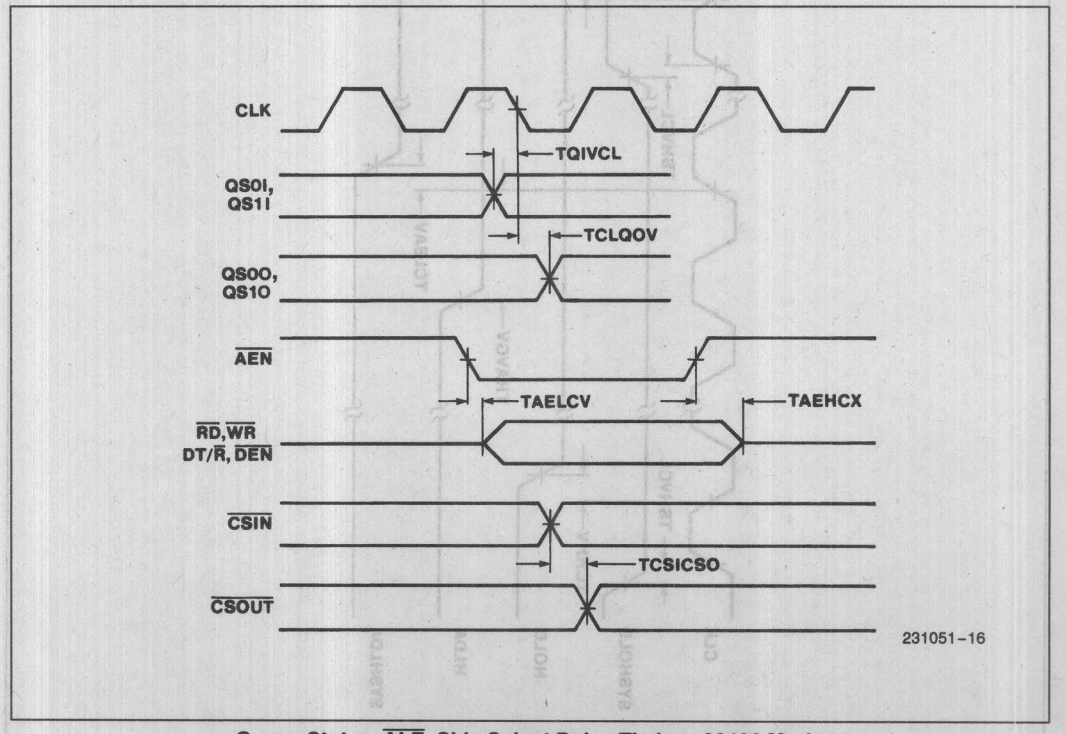
SYSHOLD-SYSHLDA to $\overline{RQ}/\overline{GT}1$ Timing–80186 Mode and 8086 Mode



SYSHOLD-SYSHLDA To HOLD-HLDA Timing–80186 Mode



RQ/GT0 to HOLD-HLDA Timing–80186 Mode



Queue Status, ALE, Chip Select Delay Timing–80186 Mode

REVISION HISTORY

The sections significantly revised since version -004 are:

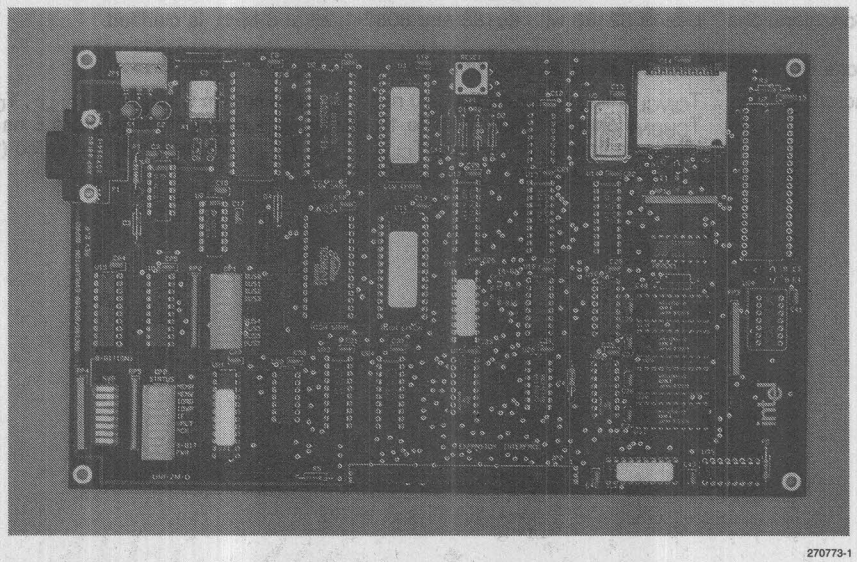
Bus Controller	Added note describing $\overline{RD}$ during $\overline{INTA}$ and DT/$\overline{R}$ compared to the 80186/80188.
System Considerations	Use of 82188 with 80186 and 8087-1, all at 8 MHz, is clarified.

The sections significantly revised since version -002 are:

AC Characteristics	T_{QIVCL} (min.) changed from 10 ns to 15 ns. Minimum timings for T_{CLML}, T_{CLMH}, and T_{CHDNV} changed from 0 ns to 10 ns. T_{CHDNX} (min.) changed from 5 ns to 10 ns. Minimum timings or T_{SVDTV}, T_{CLDTV}, and T_{CLLH} are no longer indicated (they were 0 ns). T_{CLCSOV} and T_{CLCSOH} added.

1

EV80C186 EVALUATION BOARD



270773-1

LOW COST CODE EVALUATION TOOL

Intel's EV80C186 evaluation board provides a hardware environment for code execution and software debugging at a relatively low cost. The board features the 80C186 advanced, CHMOS, 16-bit data controller, the highest performance member of the industry standard 80186 family. The board allows you to take full advantage of the power of the 80186 family. The EV80C186 provides zero wait-state, 12.5 MHz execution of your code. Plus, it can be quickly reconfigured to use an 80C188, 80186 or 80188, allowing for exact analysis of code execution speeds in a particular application.

Popular features such as single-step program execution and sixteen software breakpoints are standard on the EV80C186. Intel provides a complete code development environment using assembler (ASM-86) as well as high-level languages such as Intel's iC-86, FORTRAN-86, Pascal-86 or PL/M-86 to accelerate development schedules.

The evaluation board is hosted on an IBM PC* or BIOS-compatible clone, already a standard development solution in most of today's engineering environments. The source code for the on-board monitor (written in ASM-86) is public domain. The program is about 2K, and can be modified to be included in your target hardware. In this way, the provided PC host software can be used throughout the development phase.

November 1990
Order Number: 270773-001

FEATURES

EV80C186 FEATURES

- Zero Wait-State 12.5 MHz Execution Speed
- 16K Bytes of SRAM/ROMsim
- DRAM Sockets and Control Logic
- CMOS, low-power board
- Concurrent Interrogation of Memory and Registers
- Sixteen Software Breakpoints
- Two Single-Step Modes
- High-Level Language Support
- RS-232-C Communication Link

FULL SPEED EXECUTION

The EV80C186 executes your code from on-board ROMsim at 12.5 MHz with zero wait-states. By changing oscillators on the 80C186, any execution speed up to 16 MHz can be evaluated. The boards host interface baud-rate is not affected by this crystal change.

16K BYTES OF ROMSIM

The board comes with 16K bytes of SRAM to be used as ROMsim for your code and for data memory as needed. This memory is configured as sixteen bits wide. If you are using an 80188/80C188, the lower byte is actually a 32K x 8 SRAM, providing 32K bytes for your application.

DRAM SOCKETS AND CONTROL LOGIC

The EV80C186 comes with sockets ready for 512K bytes of DRAM; the necessary control logic is already there. Also, if you are using an 80C186 or 80C188, the monitor will set up the DRAM refresh controller for you.

TOTALLY CMOS BOARD

The EV80C186 board is built totally with CMOS components. Its power consumption is therefore low, requiring 5 volts at 400 mA. The board also requires ±12 volts at 15 mA.

CONCURRENT INTERROGATION OF MEMORY AND REGISTERS

The monitor for the EV80C186 allows you to read and modify external memory and read internal registers while your code is running in the board. You may only modify internal registers while your code is halted.

SIXTEEN SOFTWARE BREAKPOINTS

There are sixteen breakpoints available which automatically substitute an INT3 instruction for your code instruction at the breakpoint location. The substitution occurs when execution is started. If processor is halted or a breakpoint is reached, your code is restored in the ROMsim.

TWO STEP MODES

There are two single-step modes available. The first stepping mode uses the Trap Flag feature of the '86 architecture. The second mode also uses the Trap Flag except for subroutine calls which are treated as one indivisible instruction by placing an INT3 after them.

FEATURES

HIGH LEVEL LANGUAGE SUPPORT

The host software for the EV80C186 board is able to load absolute object code generated by ASM-86, iC-86, FORTRAN-86, Pascal-86 or PL/M-86, all of which are available from Intel.

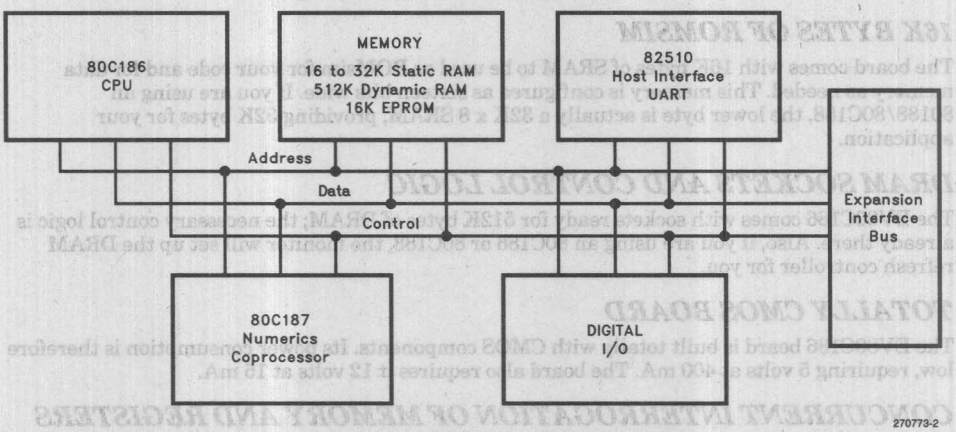
RS-232-C COMMUNICATION LINK

The EV80C186 communicates with the host using an Intel 82510 UART provided on board.

PERSONAL COMPUTER REQUIREMENTS

The EV80C186 Evaluation Board is hosted on an IBM PC, XT, AT or BIOS-compatible clone. The PC must meet the following minimum requirements:

- 512K Bytes of Memory
- One 360K Byte floppy Disk Drive
- PC DOS 3.1 or Later
- A Serial Port (COM1 or COM2) at 9600 Baud
- ASM-86, iC-86, FORTRAN-86, Pascal-86 or PL/M-86
- A text editor such as AEDIT



For information or the number of your nearest sales office call 800-548-4752 (U.S. and Canada).
Intel Corporaton, Literature Department, 3065 Bowers Avenue, Santa Clara CA 95051.

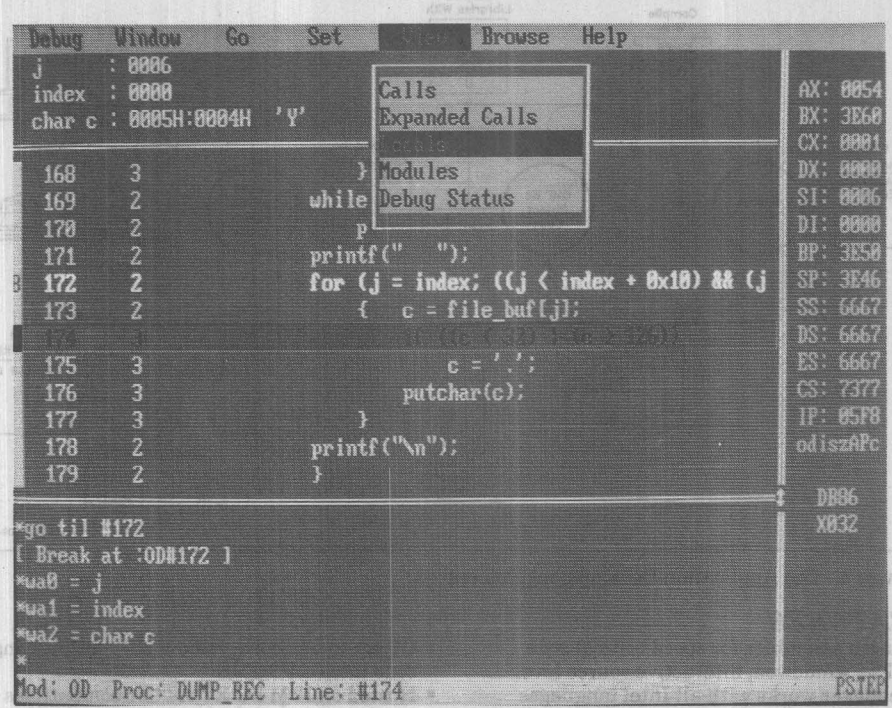
80186 Development Support Tools

2

2

80186 Development Support Tools

8086/80186 SOFTWARE DEVELOPMENT PACKAGES



280809-1

COMPLETE SOFTWARE DEVELOPMENT SUPPORT FOR THE 8086/80186 FAMILY OF MICROPROCESSORS

Intel supports application development for the 8086/80186 family of microprocessors (8086/88, 80186/188, 80C186/C188, 80C186EB/C188EB and real mode 80286 and 80386 designs) with a complete set of development languages and utilities. These tools include a macro assembler and compilers for C, PL/M, FORTRAN and Pascal. A linker/relocator program, library manager, numerics support libraries, and object-to-hex utility are also available. Intel software tools generate fast and efficient code. They are designed to give maximum control over the processor. Most importantly, they are designed to get your application up and running in an embedded system fast and with maximum design productivity.

October 1990
Order Number: 280809-003

FEATURES

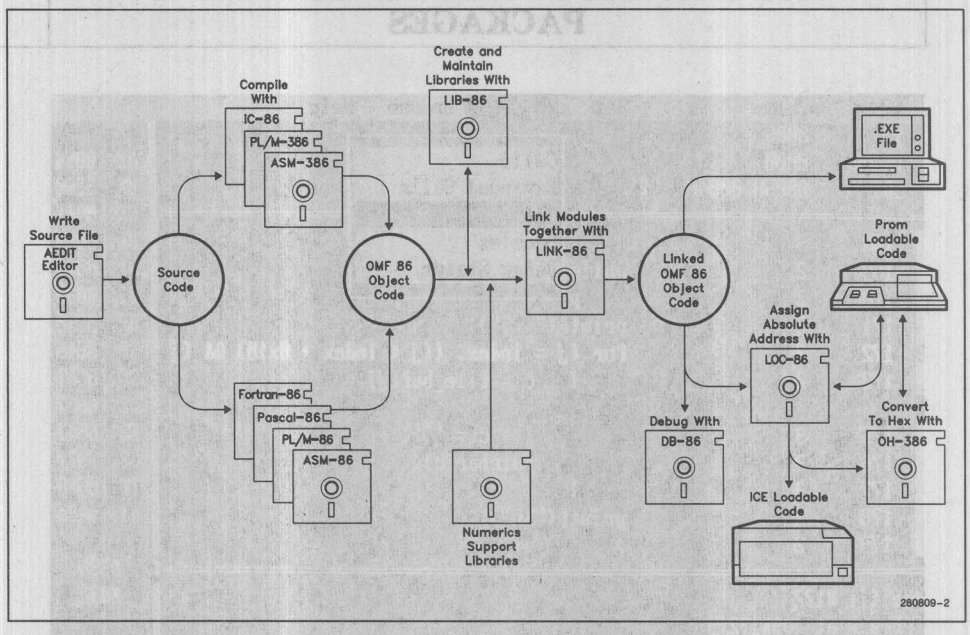


Figure 1. The Application Development Process

FEATURES

- Macro assembler for speed-critical code
- NEW windowed, interactive source level debugger works with all Intel languages
- ANSI standard iC-86 package for structured C programming, with many processor specific extensions
- PL/M compiler for high-level language programs with support for many low-level hardware functions
- FORTRAN for ANSI-compatible, numeric intensive applications
- Pascal for developing modular, portable applications that are easy to maintain
- Linker program for linking modules generated by Intel compilers and assemblers
- Locator for generating programs with absolute addresses for execution from ROM based systems
- AEDIT Source Code and text editor
- Library manager for creating and maintaining object module libraries
- Complete 8087/80C187 numeric libraries including software emulator support
- Object-to-hex conversion utility for burning code into (E)PROMS
- Hosted on IBM PC XT AT* or compatibles running DOS, DEC VAX* or MicroVAX* systems running VMS, and Intel Systems 86/3XX or 286/3XX running iRMX® Operating System

ASM-86 MACRO ASSEMBLER

ASM-86 is the macro assembler for the 8086/80186 family of components. It is used to translate symbolic assembly language source into relocatable object code where utmost speed, small code size and hardware control are critical. Intel's exclusive macro facility in ASM-86 saves development and maintenance time, since common code sequences need only be developed once. The assembler's simplified instruction set makes program development easier. This assembler also saves development time by performing extensive checks on consistent usage of variables and labels. Inconsistencies are detected when the program is assembled, before linking or debugging is started.

FEATURES

DB86 SOURCE LEVEL DEBUGGER

DB-86 is an on-host software execution environment with source level debug capabilities for object modules produced by iC-86, ASM-86, PL/M-86, Pascal-86 and FORTRAN-86. Its powerful, source-oriented interface allows users to focus their efforts on finding bugs rather than spending time learning and manipulating the debug environment.

- **Ease of learning.** Drop-down menus make the tool easy to learn for new or casual users. A command line interface is also provided for more complex problems.
- **Extensive debug modes.** Watch windows, conditional breakpoints (breakpoints triggered by program conditions), trace points, and fixed and temporary breakpoints can be set and modified as needed.
- **See into your program.** You can browse source and call stack, observe processor registers, output screen, and watch window variables accessed by either the pull down menu or by a single keystroke using function keys.
- **Full debug symbolics for maximum productivity.** The user need not know whether a variable is an unsigned integer, a real, or a structure; the debugger utilizes the wealth of variable typing information available in Intel languages to display program variables in their respective type formats.
- **Support for overlaid programs and the numeric coprocessor.**

iC-86 SOFTWARE PACKAGE

Intel's iC-86 brings the full power of the C programming language to 8086/88, 80C186/C188 and 80C186EB/C188EB-based microprocessor systems. It can also be used to develop real mode programs for execution on the 80286 or 80386. iC-86 has been developed specifically for embedded microprocessor-based applications. iC-86 meets the ANSI C standard. Key features of the iC-86 compiler include:

- **Highly Optimized.** Four levels of optimization are available. Important optimization features include a jump optimizer and improved register manipulation via register history.
- **ROMable Code and Libraries.** The iC-86 compiler produces ROMable code which can be loaded directly into embedded target systems. Libraries are also completely ROMable, retargetable and reentrant.
- **Supports Small, Medium, Compact, and Large memory segmentation models.**
- **Symbolics.** The iC-86 compiler boosts programming productivity by providing extensive debug information, including type information and symbols. The symbolics information can be used to debug using Intel ICE™ emulators and the new DB-86 Source level debugger.
- **Built-in functions.** iC-86 is loaded with built-in functions. The flags register, I/O ports, interrupts, and numerics chip can be controlled directly, without the need for assembly language coding. You spend more of your productive time programming in C and less with Assembler. Built-in functions also improve compile-time and run-time performance since the compiler generates in-line code instructions instead of function calls to assembly instructions.
- **Standard Language.** iC-86 conforms to the ANSI standard for the C language. iC-86 code is fully linkable with other modules written in other Intel 8086/186 languages, allowing programmers to use the optimal language for any task.

intel

FEATURES

PL/M-86 SOFTWARE PACKAGE

PL/M-86 is a high-level programming language designed to support the software requirements of advanced 16-bit microprocessors. PL/M-86 provides the productivity advantages of a high-level language while providing the low-level hardware access features of assembly language. Key features of PL/M-86 include:

- **Structured programming.** PL/M-86 supports modular and structured programming, making programs easier to understand, maintain and debug.
- **Built-in functions.** PL/M-86 includes an extensive list of functions, including TYPE CONVERSION functions, STRING manipulations, and functions for interrogating 8086/186 hardware flags.
- **Interrupt handling.** The INTERRUPT attribute allows you to define interrupt handling procedures. The compiler generates code to save and restore all registers for INTERRUPT procedures.
- **Compiler controls.** Compile-time options increase the flexibility of the PL/M-86 compiler. They include: optimization, conditional compilation, the inclusion of common PL/M source files from disk, cross-reference of symbols, and optional assembly language code in the listing file.
- **Data types.** PL/M-86 supports seven data types, allowing the compiler to perform three different kinds of arithmetic: signed, unsigned and floating point.
- **Language compatibility.** PL/M-86 object modules are compatible with all other object modules generated by Intel 8086/186 languages.

FORTRAN-86 SOFTWARE PACKAGE

FORTRAN-86 meets the ANSI FORTRAN 77 Language Subset Specification and includes almost all of the features of the full standard. This compatibility assures portability of existing FORTRAN programs and shortens the development process, since programmers are immediately productive without retraining.

FORTRAN-86 provides extensive support for numeric processing tasks and applications, with features such as:

- Support for single, double, double extended precision, complex, and double complex floating-point data types
- Support for proposed REALMATH IEEE floating point standard
- Full support for all other data types: integer, logical and character
- Optional hardware (8087 numeric data processor) or software (simulator) floating-point support at link time

PASCAL-86 SOFTWARE PACKAGE

Pascal-86 conforms to the ISO Pascal standard, facilitating application portability, training and maintenance. It has also been enhanced with microcomputer support features such as interrupt handling, direct port I/O and separate compilation.

A well-defined and documented run-time operating system interface allows the user to execute applications under user-designed operating systems as an alternate to the development system environment. Program modules compiled under Pascal-86 are compatible and linkable with modules written in other Intel 8086/186 languages, so developers can implement each module in the language most appropriate for the task at hand.

Pascal-86 object modules contain symbol and type information for program debugging using Intel ICE™ emulators and the DB-86 debugger.

LINK-86 LINKER

Intel's LINK-86 utility is used to combine multiple object modules into a single program and resolve references between independently compiled modules. The resulting linked module can be either a bound load-time-locatable module or simply a relocatable module. A .EXE option allows modules to be generated which can be executed directly on a DOS system.

LINK-86 greatly increases productivity by allowing you to use modular programming. The incremental link capability allows new modules to be easily added to existing software. Because applications can be broken into separate modules, they're easier to design, test and maintain. Standard modules can be reused in different applications, saving software development time.

FEATURES

LOC-86 LOCATOR

The LOC-86 utility changes relocatable 8086/186 object modules into absolute object modules. Its default address assignment algorithm will automatically assign absolute addresses to the object modules prior to loading of the code into the target system. This frees you from concern about the final arrangement of the object code in memory. You still have the power to override the control and specify absolute addresses for various Segments, Classes, and Groups in memory. You may also reserve various parts of memory.

LOC-86 is a powerful tool for embedded development because it simplifies set up of the bootstrap loader and initialization code for execution from ROM based systems. The locator will also optionally generate a print file containing diagnostic information to assist in program debugging.

NUMERICS SUPPORT LIBRARIES

The 8087 and 80C187 Support Libraries greatly facilitate the use of floating-point calculations from programs written in Assembler, PL/M, and C. It adds to these languages many of the functions that are built into applications programming languages, such as Pascal and FORTRAN. Numerics functions can be processed by either the 8087 or 80C187 numeric coprocessors, or by the corresponding software emulators. The decimal conversion library aids the translation between decimal and binary formats. A Common Elementary Function library provides support for transcendental, rounding and other common functions, not directly handled by the numeric processor. An Error Handler Module makes it easy to write interrupt routines that recover from floating-point error conditions.

LIB-86 LIBRARIAN

The Intel LIB-86 utility creates and maintains libraries of software object modules. Standard modules can be placed in a library and linked to your application using the LINK-86 utility.

AEDIT SOURCE CODE AND TEXT EDITOR

AEDIT is a full-screen text editing system designed specifically for software engineers and technical writers. With the facilities for automatic program block indentation, HEX display and input, and full macro support, AEDIT is an essential tool for any programming environment. And with AEDIT, the output file is the pure ASCII text (or HEX code) you input—no special characters or proprietary formats.

Dual file editing means you can create source code and its supporting documents at the same time. Keep your program listing with its errors in the background for easy reference while correcting the source in the foreground. Using the split-screen windowing capability, it is easy to compare two files, or copy text from one to the other. The DOS system-escape command eliminates the need to leave the editor to compile a program, get a directory listing, or execute any other program executable at the DOS system level.

OH-86 OBJECT-TO-HEXADECIMAL CONVERTER

The OH-86 utility converts Intel 8086/186 object modules into standard hexadecimal format, allowing the code to be loaded directly into PROM using industry standard PROM programmers.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, *iComments* publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

intel

ORDERING INFORMATION

LIB-86 LIBRARIAN

R286ASM86EU	FORTRAN-86	
D86ASM86KIT	ASM-86	Assembler for PC XT or AT system (or compatible) running DOS 3.0 or higher
VVSASM86	ASM-86	Assembler for VAX/VMS
MVVSASM86	ASM-86	Assembler for MicroVAX/VMS
R86ASM86SU	ASM-86	Assembler for Intel 86/3XX systems running iRMX 86 operating system
R286ASM86EU	ASM-86	Assembler for Intel 286/3XX systems running iRMX® II operating system

Note: ASM-86 includes Macro Assembler, Link-86, Loc-86, Lib-86, Cross-Reference utility, OH-86, Numerics Support, and DB-86 Source Level Debugger. (DB-86 available in DOS version only.)

D86C86NL	iC-86	Software Package for IBM PC XT/AT running PC DOS 3.0 or higher
VVSC86	iC-86	Software Package for VAX/VMS
MVVSC86	iC-86	Software Package for MicroVAX/VMS
VVSPLM86	PL/M-86	Software Package for VAX/VMS
MVVSPLM86	PL/M-86	Software Package for MicroVAX/VMS
R86PLM86SU	PL/M-86	Software Package for Intel System 8086/3XX running iRMX 86 operating system
D86FOR86NL	FORTRAN-86	Software Package for PC XT AT (or compatible) running PC-DOS 3.0 or higher
VVSFORT86	FORTRAN-86	Software Package for VAX/VMS 4.3 and later
MVVSFORT86	FORTRAN-86	Software Package for MicroVAX/VMS
R86FOR86SU	FORTRAN-86	Software Package for Intel System 86/3XX running iRMX 86 operating system
D86PAS86NL	PASCAL-86	Software Package for IBM PC XT AT running PC DOS 3.0 or higher
VVSPAS86	PASCAL-86	Software Package for VAX/VMS

ORDERING INFORMATION

R86C86SU	iC-86	Software Package for Intel System 8086/3XX running iRMX 86 operating system
D86PLM86NL	PL/M-86	Software Package for IBM PC XT AT running PC DOS 3.0 or higher
MVVPAS86	PASCAL-86	Software Package for MicroVAX/ VMS
R86PAS86SU	PASCAL-86	Software Package for Intel System 86/3XX running iRMX 86
D86EDNL		AEDIT Source Code Editor for IBM PC XT/AT running PC DOS 3.0 or higher

iPAT™ PERFORMANCE ANALYSIS TOOL

280786-1

REAL-TIME SOFTWARE ANALYSIS FOR THE 8086/88, 80186/188, 80286, and 80386

Intel's iPAT™ Performance Analysis Tool enables OEMs developing applications based on the 8086/88, 80186/188, 80286, or 80386 microprocessors to analyze real-time software execution in their prototype systems at speeds up to 20 MHz. Through such analysis, it is possible to speed-tune applications with real-time data, optimize use of operating systems (such as Intel's iRMX® II Real-Time Multitasking Executive for the 80286 and 80386, and iRMK™ Real-Time Multitasking Kernel for the 80386), characterize response characteristics, and determine code execution coverage by real-time test suites. Analysis is performed symbolically, non-intrusively, and in real-time with 100% sampling in the microprocessor prototype environment. iPAT supports analysis of OEM-developed software built using 8086, 80286, and 80386 assemblers and compilers supplied by Intel and other vendors.

All iPAT Performance Analysis Tool products are serially linked to DOS computer systems (such as IBM* PC AT, PC XT, and PS/2* Model 80) to host iPAT control and graphic display software. Several means of access to the user's prototype microprocessor system are supported. For the 80286 (real and protected mode), a 12.5 MHz iPAT-286 probe can be used with the iPATCORE system. For the 8086/88 (MAX MODE designs only), a 10 MHz iPAT-88 probe can be used with the iPATCORE system. iPATCORE systems also can be connected to sockets provided on the ICE™-286 and ICE-186 in-circuit emulators, or interfaced to I²ICE™ in-circuit emulators with probes supporting the 8086/88, 80186/188, or 80286. The 20 MHz iPAT-386 probe, also supported by the common iPATCORE system, can be operated either in "piggyback" fashion connected to an Intel ICE in-circuit emulator for the Intel386, or directly connected to a prototype system independent of an ICE. iPAT-386 supports all models of 80386 applications anywhere in the lowest 16 Megabytes of the 80386 linear address space.

November 1990
Order Number: 280786-003

FEATURES

iPAT™ FEATURES

- Up to 20 MHz real-time analysis
- Histograms and analysis tables
- Performance profiles of up to 125 partitions
- Code execution coverage over up to 252K
- Hardware or software interrupt analysis
- Simple use with function keys and graphics
- Use with or without Intel ICEs

MOST COMPLETE REAL-TIME ANALYSIS AVAILABLE TODAY

iPAT Performance Analysis Tools use in-circuit probes containing proprietary chip technology to achieve full sampling in real-time non-intrusively.

MEETS THE REAL-TIME DESIGNER'S NEEDS

The iPAT products include support for interactions between real-time software and hardware interrupts, real-time operating systems, "idle time," and full analysis of real-time process control systems.

SPEED-TUNING YOUR SOFTWARE

By examining iPAT histogram and tabular information about procedure usage (including or not including their interaction with other procedures, hardware, operating systems, or interrupt service routines) for critical functions, the software engineer can quickly pinpoint trouble spots. Armed with this information, bottlenecks can be eliminated by means such as changes to algorithms, recoding in assembler, or adjusting system interrupt priorities. Finally, iPAT can be used to prove the acceptability of the developer's results.

EFFICIENCY AND EFFECTIVENESS IN TESTING

With iPAT code execution coverage information, product evaluation with test suites can be performed more effectively and in less time. The evaluation team can quickly pinpoint areas of code that are executed or not executed under real-time conditions. By this means, the evaluation team can substantially remove the "black box" aspect of testing and assure 100% hits on the software under test. Coverage information can be used to document testing at the module, procedure, and line level. iPAT utilities also support generation of instruction-level code coverage information.

ANALYSIS WITH OR WITHOUT SYMBOLICS

If your application is developed with "debug" symbolics generated by Intel 8086, 80286, or 80386 assemblers and compilers, iPAT can use them—automatically. Symbolic names also can be defined within the iPAT environment, or conversion tools supplied with the iPAT products can be used to create symbolic information from virtually any vendor's map files for 8086, 80286, and 80836 software tools.

REAL OR PROTECTED MODE

iPAT supports 80286 and 80386 protected mode symbolic information generated by Intel 80286 and 80386 software tools. It can work with absolute addresses, as well as base-offset or selector-offset references to partitions in the prototype system's execution address space.

FROM ROM-LOADED TO OPERATING SYSTEM LOADED APPLICATIONS

The software analysis provided by iPAT watches absolute execution addresses in-circuit in real time, but also supports use of various iPAT utilities to determine the load locations for load-time located software, such as applications running under iRMXII, DOS, Microsoft Windows*, or MS*-OS/2.

USE STANDALONE OR WITH ICE

The iPAT-386, iPAT-286, and iPAT-86/88 probes, together with an iPATCORE system, provide standalone software analysis independent of an ICE (in-circuit emulator) system. The iPATCORE system and DOS-hosted software also can be used together with ICE-386, ICE-286, and I²ICE-86/88, 186/188, or 286 in-circuit emulators and DOS-hosted software. Under the latter scenario, the user can examine prototype software characteristics in real-time on one DOS host while another DOS host is used to supply input or test conditions to the prototype through an ICE.

intel

FEATURES

UTILITIES FOR YOUR NEEDS

Various utilities supplied with iPAT products support generation of symbolic information from map files associated with 3rd-party software tools, extended analysis of iPAT code execution coverage analysis data, and convenience in the working environment. For example, symbolics can be generated for maps produced by most software tools, instruction-level code execution information can be produced, and iRMXII-format disks can be read/written in DOS floppy drives to facilitate file transfer.

WORLDWIDE SERVICE AND SUPPORT

All iPAT Performance Analysis Tool products are supported by Intel's worldwide service and support. Total hardware and software support is available, including a hotline number when the need is there.

SPECIFICATIONS

HOST COMPUTER REQUIREMENTS

All iPAT Performance Analysis Tool products are hosted on IBM PC AT, PC XT, or PS/2 Model 80 personal computers, or 100% compatibles, and use a serial link for host-to-iPAT communications. At least a PC AT class system is recommended. The DOS host system must meet the following minimum requirements:

- 640K Bytes of Memory
- 360K Byte or 1.2M Byte floppy disk drive
- Fixed disk drive
- A serial port (COM1 or COM2) supporting 9600 baud data transfer
- DOS 3.0 or later
- IBM or 100% compatible BIOS

PHYSICAL DESCRIPTIONS

Unit	Width In.	Width Cm.	Height In.	Height Cm.	Length In.	Length Cm.
iPATCORE	8.25	21.0	1.75	4.5	13.75	35.0
Power Supply	7.75	20.0	4.25	11.0	11.0	28.0
iPAT-386 probe	3.0	7.6	0.50	1.3	4.0	10.1
iPAT-286 probe	4.0	10.2	1.12	2.8	6.0	15.3
iPAT-86 probe	4.0	10.2	1.12	2.8	6.0	15.3
iPATCABLE (to ICE-186/286)	4.0	10.2	.25	.6	36.0	91.4
IIIPATB,C,D (I^2ICE board)	12.0	30.5	12.0	30.5	.5	1.3
Serial cables PC AT/XT PS/2					144.0	370.0

ELECTRICAL CONSIDERATIONS

The iPATCORE system power supply uses an AC power source at 100V, 120V, 220V, or 240V over 47Hz to 63Hz. 2 amps (AC) at 100V or 120V; 1 amp at 220V or 240V.

iPAT-386, iPAT-286 and iPAT-86/88 probes are externally powered, impose no power demands on the user's prototype, and can thus be used to analyze software activity through power down and power up of a prototype system. For ICE-386, ICE-286, ICE-186, and I^2ICE microprocessor probes, see the appropriate in-circuit emulator factsheets.

ENVIRONMENTAL SPECIFICATIONS

Operating Temperature: 10°C to 40°C (50°F to 104°F) ambient

Operating Humidity: Maximum of 85% relative humidity, non-condensing

SPECIFICATIONS

CONFIGURATION GUIDE

For all of the following application requirements, the iPAT system is supported with iPAT 2.0 (or greater) or iPAT/I²ICE 1.2 (or greater) host software, as footnoted.

Application Software	Option	iPAT Order Codes	Host System
80386 Embedded	#1	iPAT386DOS[1], iPATCORE	DOS[4]
iRMK on 80386	#1	iPAT386DOS, iPATCORE	DOS
iRMXII OS-Loaded or Embedded on 386	#1	iPAT386DOS, iPATCORE	DOS
OS/2-Loaded on 386	#1	iPAT386DOS, iPATCORE	DOS
iRMXII OS-Loaded or Embedded	#1	iPAT286DOS, iPATCORE	DOS
80286 Embedded	#1	iPAT286DOS, iPATCORE	DOS
	#2	ICEPATKIT[2]	DOS
	#3	I²ICEPATKIT[3]	DOS
	#4	IIIPATD, iPATCORE[3]	DOS[4]
DOS OS-Loaded 80286	#1	iPAT286DOS, iPATCORE	DOS
OS/2 OS-Loaded 80286	#1	iPAT286DOS, iPATCORE	DOS
80186/188 Embedded	#1	ICEPATKIT[2]	DOS
	#2	I²ICEPATKIT[3]	DOS
	#3	IIIPATD, iPATCORE[3]	DOS[4]
DOS OS-Loaded 8086/88	#1	iPAT88DOS, iPATCORE	DOS
8086/88 Embedded	#1	iPAT88DOS, iPATCORE	DOS
	#2	I²ICEPATKIT[3]	DOS
	#3	IIIPATD, iPATCORE[3]	DOS[4]

Notes:

1. Operable standalone or with ICE-386 (separate product; separate host). iPAT-386 probe connects directly to prototype system socket, or to optional 4 probe-to-socket hinge cable (order code TA386A), or to ICE-386 probe socket.
2. Requires ICE-186 or ICE-286 in-circuit emulator system.
3. Requires I²ICE in-circuit emulator system.
4. Includes iPAT/I²ICE integrated software (iPAT/ICE 1.2 or greater), which only supports sequential iPAT and ICE operation on one host, rather than in parallel on two hosts (iPAT 2.0 or greater).

I²ICE™ IN-CIRCUIT EMULATION SYSTEM

280800-1

IN-CIRCUIT EMULATOR FOR THE 8086/80186/80286 FAMILY OF MICROPROCESSORS

The I²ICE™ In-circuit Emulator is a high-performance, cost-effective debug environment for developing systems with the Intel 8086/80186/80286 family of microprocessors. With 10 MHz emulation, a window-oriented user interface, and compatibility with Intel's iPAT™ Performance Analysis Tool, the I²ICE Emulator gives you unmatched speed and control over all phases of hardware/software debug.

FEATURES

- Emulation speeds up to 10 MHz with 8086/88, 80186/188 and 80286 microprocessors
- 8087 and 80287 numeric coprocessor support
- Hosted on IBM PC AT* or AT BIOS compatibles
- ICEVIEW™ window-oriented user interface with pull-down menus and context-sensitive help
- Source and symbol display using all Intel languages
- 1K frame bus and execution trace buffer
- Symbolic debugging for flexible access to memory location and program variables
- Flexible breakpointing for quick problem isolation
- Memory expandable to 288K with zero wait states
- Worldwide service and support
- iPAT option for software speed tuning

I²ICE, ICEVIEW, and iPAT are trademarks of Intel Corporation.
*IBM is a trademark of International Business Machines Corporation.

November 1990
Order Number: 280800-003

FEATURES

ONE TOOL FOR THE ENTIRE DEVELOPMENT PROCESS

The I²ICE Emulator allows hardware and software design to proceed simultaneously, so you can develop software even before prototype hardware is available. With 32K of zero wait-state mappable memory (and an additional 256K with optional memory boards), you can use the I²ICE Emulator to debug at any stage of the development cycle: hardware development, software development, system integration or system test.

HIGH-SPEED, REAL-TIME EMULATION

The I²ICE Emulator delivers full-speed, real-time emulation at speeds up to 10 MHz. Based on Intel's exclusive microprocessor technology, the I²ICE Emulator matches each chip's electrical and timing characteristics without memory or interrupt intrusions, ensuring design accuracy and eliminating surprises. The performance of your prototype is the performance you can expect from your final product.

EASY-TO-USE ICEVIEW™ INTERFACE

The ICEVIEW interface makes the I²ICE Emulator easy to learn and use by providing easy access to application information and ICE functions. Pull-down menus and windows boost productivity for both new and experienced users. Multiple on-screen windows allow you to access the source display, execution trace, register, and other important information, all at the same time. You can watch the information change as you modify and step through your program. You can even customize window size and screen positions. A command line interface is also available with syntax checking and context-sensitive prompts. ICEVIEW works with monochrome, CGA and the latest EGA color displays.

SYMBOLIC DEBUG SPEEDS DEVELOPMENT

The extensive debug symbolics generated by the Intel 8086 and 80286 assemblers and compilers can increase your development productivity. Symbolics with automatic formatting are available for all primitive types, regardless of whether the variables are globals, locals (stack-resident) or pointers. The virtual symbol table supports all symbolics, even in very large programs. Aliasing can be used to reduce keystrokes and save time.

POWERFUL BREAK AND TRACE CAPABILITY FOR FAST PROBLEM ISOLATION

The I²ICE Emulator allows up to eight simultaneous break/trace conditions to be set (four execution, four bus), a timesaver when solving hardware/software integration problems. Break and trace points can be set on specified line numbers, on procedures, or on symbolic data events, such as writing a variable to a value or range of values. You can break or trace on specific hardware events, such as a read or write to a specific address, data or I/O port, or on a combination of events.

MULTIPROCESSOR, PROTECTED MODE, AND COPROCESSOR SUPPORT

Up to four I²ICE systems can be linked and controlled simultaneously from one PC host, enabling you to debug multiprocessor systems. The I²ICE Emulator with an 80286 probe supports all 80286 protected mode capabilities. It also supports the 8087 and 80287 numeric coprocessors.

FEATURES

iPAT™ FOR SOFTWARE PERFORMANCE AND CODE COVERAGE ANALYSIS

The I²ICE Emulator interfaces to Intel's iPAT Performance Analysis Tool for examining software execution speeds and code coverage in real time. iPAT displays critical performance data about your code in easy-to-understand histograms and tables. Elusive bottlenecks are readily seen, allowing you to focus your attention to get the most performance out of your product.

iPAT also performs code execution coverage, letting you perform product evaluations faster and more effectively. iPAT pinpoints areas in your code either executed or not executed according to specific conditions, taking the guesswork out of software evaluations.

EASY INTERFACE TO EXTERNAL INSTRUMENTS

The I²ICE system includes external emulation clips and software support for setting breakpoints, tracepoints and arm/disarm conditions on external events, making it easy to connect external logic analyzers and signal generators. You can debug complex hardware/software interactions with a high level of productivity.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, *iComments* publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

SPECIFICATIONS

Host Requirements

IBM PC/AT or 100% PC AT BIOS compatible
DOS 3.XX
640 Kbytes of memory
360 Kbytes or 1.2 MB floppy disk drive
Hard disk drive
Monochrome, CGA or EGA monitor (EGA recommended)

Physical Description

	Width		Height		Length	
Unit	cm	in	cm	in	cm	in
I²ICE chassis	43.2	17.0	21.0	8.25	61.3	24.13
Probe base	21.6	8.5	7.6	3.0	25.4	10.0

Host/chassis cable15 ft. (4.6 m)

Electrical Characteristics

90-132 V or 180-264 V (selectable)
47-63 Hz
12 amps (AC)

Environmental Specifications

Operating temperature: 0-40°C (32-104°F) ambient
Operating humidity: Maximum of 85% relative humidity, non-condensing

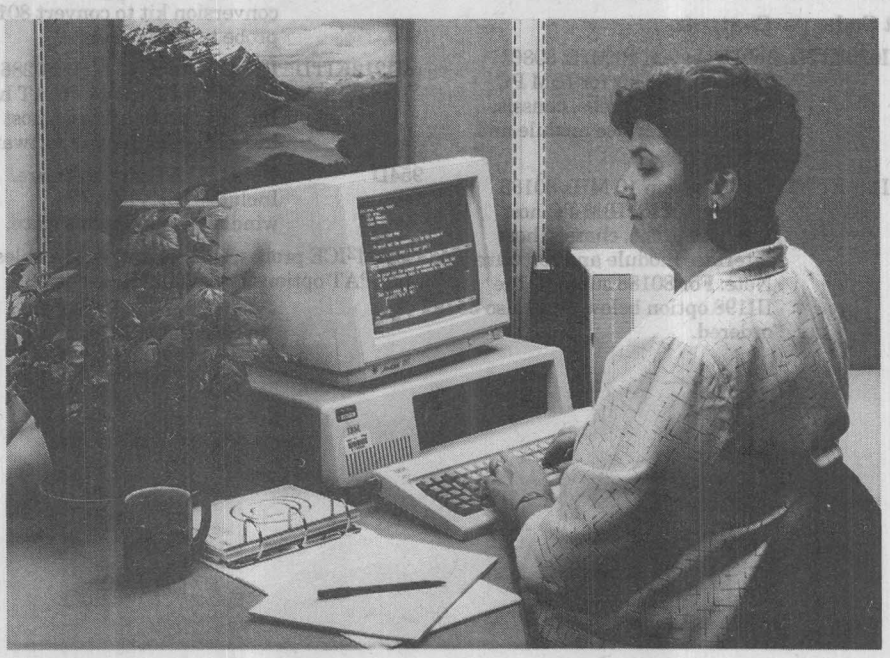
FEATURES

ORDERING INFORMATION

Kit Code	Contents
pIII010KITD	I²ICE system 10 MHz 8086/8088 support kit for IBM PC host. Includes probe, chassis, and host interface module and software.
pIII111KITD	I²ICE system 10 MHz 80186 support kit for IBM PC host. Includes probe, chassis, host interface module and software. Note: For 80188 support, the III198 option below must also be ordered.
III198	8 MHz 80188 support conversion kit to convert 80186 probe to 80188 probe.
pIII212KITD	I²ICE system, 10 MHz 80286 support kit for IBM PC AT host. Includes probe, chassis, host interface module and software.
954D	I²ICE PC AT host software. Includes ICEVIEW™ windowed human interface.

Note: I²ICE probes, chassis, software, cables and iPAT options are available separately.

AEDIT SOURCE CODE AND TEXT EDITOR



280804-1

PROGRAMMER SUPPORT

AEDIT is a full-screen text editing system designed specifically for software engineers and technical writers. With the facilities for automatic program block indentation, HEX display and input, and full macro support, AEDIT is an essential tool for any programming environment. And with AEDIT, the output file is the pure ASCII text (or HEX code) you input—no special characters or proprietary formats.

Dual file editing means you can create source code and its supporting documents at the same time. Keep your program listing with its errors in the background for easy reference while correcting the source in the foreground. Using the split-screen windowing capability, it is easy to compare two files, or copy text from one to the other. The DOS system-escape command eliminates the need to leave the editor to compile a program, get a directory listing, or execute any other program executable at the DOS system level.

There are no limits placed on the size of the file or the length of the lines processed with AEDIT. It even has a batch mode for those times when you need to make automatic string substitutions or insertions in a number of separate text files.

AEDIT FEATURES

- Complete range of editing support—from document processing to HEX code entry and modification
- Supports system escape for quick execution of PC-DOS System level *commands*
- Full macro support for complex or repetitive editing tasks
- Hosted on PC-DOS and RMX operating systems
- Dual file support with optional split-screen windowing
- No limit to file size or line length

October 1990
Order Number: 280804-002

FEATURES

- Quick response with an easy to use menu driven interface
- Configurable and extensible for complete control of the editing process

POWERFUL TEXT EDITOR

As a text editor, AEDIT is versatile and complete. In addition to simple character insertion and cursor positioning commands, AEDIT supports a number of text block processing commands. Using these commands you can easily move, copy, or delete both small and large blocks of text. AEDIT also provides facilities for forward or reverse string searches, string replacement and query replace.

AEDIT removes the restriction of only inserting characters when adding or modifying text. When adding text with AEDIT you may choose to either insert characters at the current cursor location, or over-write the existing text as you type. This flexibility simplifies the creation and editing of tables and charts.

USER INTERFACE

The menu-driven interface AEDIT provides makes it unnecessary to memorize long lists of commands and their syntax. Instead, a complete list of the commands or options available at any point is always displayed at the bottom of the screen. This makes AEDIT both easy to learn and easy to use.

FULL FLEXIBILITY

In addition to the standard PC terminal support provided with AEDIT, you are able to configure AEDIT to work with almost any terminal. This along with user-definable macros and full adjustable tabs, margins, and case sensitivity combine to make AEDIT one of the most flexible editors available today.

MACRO SUPPORT

AEDIT will create macros by simply keeping track of the command and text that you type, "learning" the function the macro is to perform. The editor remembers your actions for later execution, or you may store them in a file to use in a later editing session.

Alternatively, you can design a macro using AEDIT's powerful macro language. Included with the editor is an extensive library of useful macros which you may use or modify to meet your individual editing needs.

TEXT PROCESSING

For your documentation needs, paragraph filling or justification simplifies the chore of document formatting. Automatic carriage return insertion means you can focus on the content of what you are typing instead of how close you are to the edge of the screen.

SERVICE, SUPPORT, AND TRAINING

Intel augments its development tools with a full array of seminars, classes, and workshops; on-site consulting services; field application engineering expertise; telephone hot-line support; and software and hardware maintenance contracts. This full line of services will ensure your design success.

SPECIFICATIONS

HOST SYSTEM

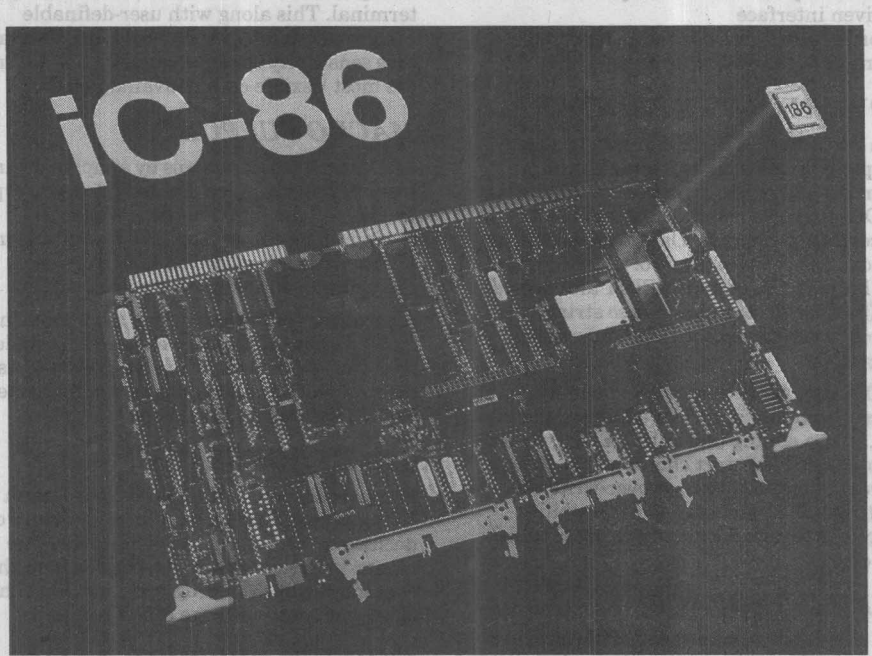
AEDIT for PC-DOS has been designed to run on the IBM* PC XT, IBM PC AT, and compatibles. It has been tested and evaluated for the PC-DOS 3.0 or greater operating system.

Versions of AEDIT are available for the iRMX™-86 and iRMX II Operating System.

ORDERING INFORMATION

D86EDINL	AEDIT Source Code Editor Release 2.2 for PC-DOS with supporting documentation
122716	AEDIT-DOS Users Guide
122721	AEDIT-DOS Pocket Reference
RMX864WSU	AEDIT for iRMX I Operating System
R286EDI286EU	AEDIT for iRMX II/III Operating System

INTEL iC-86/286 C COMPILER



280787-1

INTEL iC-86/286 COMPILER

The Intel iC-86/286 compiler is the C compiler to use for 8086/186/286 embedded microprocessor designs. In addition to outstanding execution speed, Intel's iC-86/286 compiler generates compact, efficient code which can be easily loaded into ROM-based systems. The iC-86/286 compiler is also fully supported by the Intel DB86 windowed source-level software debugger and in-circuit emulation tools.

iC-86/286 COMPILER FEATURES

- Optimized for embedded systems
- Built-in functions for automatic machine code generation
- ROMable code and libraries
- Integrated debugging with Intel ICE™ and I²ICE™
- Compliance with draft ANSI standard
- Supports Small, Medium, Compact, and Large memory models
- PL/M compatible subsystems
- Selector data type support
- Linkable with other Intel 8086/286 languages such as ASM and PL/M
- ROMable and reentrant libraries
- Ability to mix memory models with "near" and "far" pointers
- C and PL/M calling conventions for compatibility with PL/M and other C programs
- iRMX® interface libraries included

ICE™, iRMX™, 386™, iPAT™, and I²ICE™ are trademarks of Intel Corporation.

November 1990
Order Number: 280787-002

FEATURES

BUILT-IN FUNCTIONS

The iC-86/286 compiler features more than 35 processor-specific functions that directly generate machine code within the C language.

Built-in functions eliminate the need for in-line assembly language coding or making calls to assembly functions. This increases code performance and reduces programming time.

With built-ins you can enable or disable interrupts and directly control hardware I/O without having to exit C for assembler. This means you can write high performance software for real time applications without having to keep track of every architectural detail, as you would in assembly language. For example, to generate an INT instruction, you simply type:

```
causeinterrupt (number)
```

Or, the following iC-86 instruction will cause the processor to come to a halt with interrupts enabled:

```
halt( )
```

EMBEDDED COMPONENT SUPPORT

iC-86/286 compiler was designed specifically for embedded microprocessor applications. It produces ROMable code which can be loaded directly into target systems via Intel ICE emulators and debugged *without modification* for fast, easy, development and debugging.

HIGHLY OPTIMIZED

The iC-86/286 compiler has four levels of optimization for tailoring performance to your application. Important optimization features include a jump optimizer and improved register manipulation using register history.

RUN-TIME SUPPORT

Run-time libraries for the iC-86/286 compiler are designed for use in many environments. Both DOS and iRMX interface libraries are included so programs executing on those systems can take advantage of operating system features. The interface libraries conform to the ANSI standard. They also meet the IEEE standard POSIX interface so you can easily retarget the libraries for use in applications that do not run on DOS or iRMX.

The libraries are completely ROMable and re-entrant making it easy to adapt them for embedded, multi-tasking or real-time applications.

Both the DOS and iRMX-I operating system interface libraries are provided with iC-86 hosted on DOS. The iRMX-I hosted version of iC-86 includes the iRMX interface libraries only.

iC-286 compiler includes iRMX-II interface libraries only.

INTEGRATED DEBUG TOOLS

The iC-86/286 compiler is part of a completely integrated set of development tools from Intel (Figure 1).

Code output from the compiler can be easily linked with modules written in assembler and high-level languages, such as PL/M, Fortran, and Pascal.

Linked modules and programs can be debugged using Intel's DB86 windowed source-level software debugger. The debugger uses an advanced interface with windows and pull-down menus for the ultimate in debug productivity. Watch windows can be opened to observe changing program variables and processor registers. You can readily switch between program modules and view the calling sequence and call stack.

Naturally code generated by iC-86/286 works completely with Intel's I2ICE, ICE-186, ICE-286 and ICE-386 family of in-circuit emulators as well as the iPAT(tm) performance analysis tool. This complete set of tools gives you the power to quickly debug, test, integrate and optimize your application code for the target system.

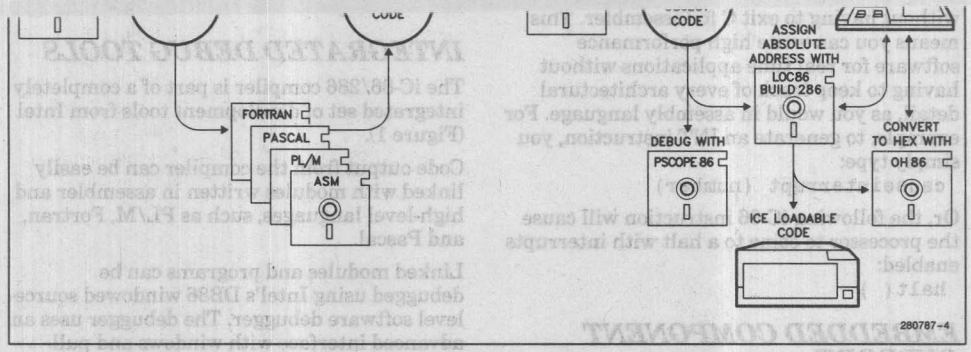


Figure 1: The Application Development Process

SERVICE AND SUPPORT

Intel's development tools are backed by our worldwide service and support organization dedicated to solving any problems encountered by our customers. Several hardware and software service programs are available which include hotline support, consulting, training, technical newsletters, bulletin boards and other services. The iC-86/286 compiler includes 90 days of software support under warranty.

SPECIFICATIONS

ENVIRONMENT

Hardware Requirements	DOS Version:	IBM PC XT or AT (or 100% Compatible) running DOS 3.1 or greater.
	iRMX Version:	iRMX-I system for iC-86 iRMX-II system for iC-286
Memory Requirements	DOS Version:	256 KB
	iRMX Version:	374 KB
Media	DOS Version:	5¼" DS/DD Diskettes 3½" DS/DD *Diskettes*
	iRMX Version:	DS/DD iRMX Standard Format

STANDARDS

iC-86/286 conforms to the X3J11 ANSI draft proposal for the C programming language.

SPECIFICATIONS

ORDERING INFORMATION

Order Code	Host Environment	Target Code
D86C86NL	DOS	8086/186
D86C286NL	DOS	80286
R86C86	iRMX-I	8086/186
R286C286	iRMX-II	80286

Other programming tools:

Order Code	Host Environment	Description
D86PAK86NL	DOS	8086/186 Assembler, DB86 Debugger, Utilities AEDIT text editor
D86ASM86KIT	DOS	8086/186 Assembler, DB86 Debugger, Utilities
D86ASM286NL	DOS	80286 Assembler
R86ASM86	iRMX-I	8086/186 Assembler, Utilities
R286ASM286	iRMX-II	80286 Assembler, Utilities
RMXIISFTSCP	iRMX-II	80286 Soft-Scope Debugger

INTEL ICE™-186 AND ICE-188 IN-CIRCUIT EMULATORS

280726-1

HIGH PERFORMANCE REAL-TIME EMULATION

The Intel ICE™-186 and ICE™-188 emulators deliver reliable 16 MHz real-time emulation for the 80C186 and 80C188 microprocessors. The 80C186 and 80C188 embedded processors are based on the new 80C186 modular CPU core with fully-static design. The in-circuit emulators are a versatile and efficient tool for developing, debugging and testing products designed with Intel microprocessors. The ICE-186/188 has many productivity boosting features to help you get your products to market as quickly as possible. The contemporary windowed human interface, symbolic source-level debug, 3K frames of dynamic trace display and the powerful conditional break capabilities are standard on the ICE-186/188 emulator. Intel, the inventor of the 80C186 and 80C188 microprocessors, has the most complete line of development tools from a single vendor to meet all of your development needs. Our language development tools portfolio includes the assembler, software debugger DB-86, C, PL/M, PASCAL and FORTRAN, all designed to work with the ICE-186/188 emulator to meet your embedded design needs.

November 1990
Order Number: 280726-005

FEATURES

ICE™-186/188 FEATURES

- Reliable Full Speed Emulation up to 16 MHz
- 3K Frames Dynamic Trace Buffer can be displayed without stopping emulation
- Optional 128K, 512K or 1 Mbyte of Zero Wait-State Mapped Memory
- 80C187 Numeric Coprocessor Support
- High Speed RS-232-C and GPIB Communication Link
- Crystal Power Accessory for Software Development
- Interface for Intel Performance Analysis Tool (iPAT™) and Logic Analyzer
- Emulation and ONCE™ Mode Support for QFP and PLCC Packages
- Windowed Human Interface with Mouse Support
- Source Level Debug with effective Source Window and Watch Window Operations
- Powerful Go Command with two-level breakpoints, event counters and single stepping capability
- High-Level Language Symbolic Debug
- Tutorial Software to Speed Up Learning Curve
- Complete Intel Service and Support

SOFTWARE PERFORMANCE ANALYSIS

Intel's Performance Analysis Tool (iPAT) is designed to increase the team productivity with features such as interrupt latency measurement, code coverage analysis and software module timing analysis. The emulator provides an external connector for the iPAT tool. These features enable the user to design reliable, high performance embedded control products.

BUILT-IN SUPPORT FOR LOGIC ANALYZERS

General purpose logic analyzers can be used with the ICE-186/188 emulator to provide detailed timing of specific events. The emulator has an external sync signal to trigger the logic analyzer, making complex event triggering easy. An additional 60 pin connector is included to support the logic analyzer.

SOFTWARE CARROUSEL

To address the need of switching among different development tools, such as editing, recompilation and linking with minimum interruptions, the Software Carrousel package is included. It provides an environment which allows up to eleven other programs to be accessible while running the emulator software. By pressing a pair of keys, the current program environment is preserved and a different application environment is ready.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and works, field application engineering expertise, hotline technical support and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, *iComments* publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site support.

SPECIFICATIONS

PERSONAL COMPUTER REQUIREMENTS

The ICE-186/188 emulator is hosted on an IBM PC AT platform or IBM PS/2. The emulator has been tested and evaluated on an IBM PC AT. The PC AT must meet the following minimum requirements:

- 640 KBytes of Memory
- An additional 1 MByte of expanded memory, recommending an Above Board managed by emm.sys driver. Other memory managers conforming to the Lotus/Intel/Microsoft Expanded Memory Specification Version 3.2 or later are available.
- One 20 MByte Hard Disk
- PC DOS 3.2 or Later
- A serial Port (COM1 or COM2) supporting minimally at 9600 Baud Data Transfers, or a National Instruments GPIB-PC2A board
- Math coprocessor

ORDERING INFORMATION

ICE186LP	ICE-186 16 MHz system, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adaptor and ONCE adaptor
ICE186LQ	ICE-186 16MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adaptor
ICE188LP	ICE-188 16 MHz System, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adaptor and ONCE adaptor
ICE188LQ	ICE-188 16MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adaptor

The above order codes must order a memory option

MEM128	128 Kbytes map memory
MEM512	512 Kbytes map memory
MEM1MB	1 Mbytes map memory
UP186LP	ICE-186 PLCC Probe
UP186LQ	ICE-186 QFP Probe
UP188LP	ICE-188 PLCC Probe
UP188LQ	ICE-188 QFP Probe
HC18XLP	PLCC hinge cable
HC18XLQ	QFP hinge cable
D86ASM86KIT	Assembler, Link-86, Loc-86, Lib 86, cross reference utility, OH-86, numerics support, software debugger, hosted on PC DOS 3.0 or higher
D86C86NL	C-86 compiler for PC DOS 3.0 or higher
D86PLM86NL	PL/M-86 compiler for PC DOS 3.0 or higher
D86PAS86NL	PASCAL-86 compiler for PC DOS 3.0 or higher
D86FOR86NL	FORTRAN-86 compiler for PC DOS 3.0 or higher
*D86ASM86NL	ASM-86 Macro Assembler

*European customers only

INTEL ICE™-186EB AND ICE-188EB IN-CIRCUIT EMULATORS

HIGH PERFORMANCE REAL-TIME EMULATION

The Intel ICE™-186EB and ICE™-188EB emulators deliver reliable 16 MHz real-time emulation for the 80C186EB and 80C188EB microprocessors. The in-circuit emulators are a versatile and efficient tool for developing, debugging and testing products designed with Intel microprocessors. The ICE-186EB/188EB has many productivity boosting features to help you get your products to market as quickly as possible. The contemporary windowed human interface, symbolic source-level debug, 3K frames of dynamic trace display and the powerful conditional break capabilities are standard on the ICE-186EB/188EB emulator. Intel, the inventor of the 80C186EB and 80C188EB microprocessors, has the most complete line of development tools from a single vendor to meet all of your development needs. Our language development tools portfolio includes the assembler, software debugger DB-86, C, PL/M, PASCAL and FORTRAN, all designed to work with the ICE-186EB/188EB emulator to meet your embedded design needs.

ICE™-186EB/188EB FEATURES

- Reliable Full Speed Emulation up to 16 MHz
- 3K Frames Dynamic Trace Buffer can be displayed without stopping emulation
- Optional 128K, 512K or 1 Mbytes of Zero Wait-State Mapped Memory*
- 80C187 Numeric Coprocessor Support
- High Speed RS-232-C and GPIB Communication Link
- Crystal Power Accessory for Software Development
- Interface for Intel Performance Analysis Tool (iPAT™) and Logic Analyzer
- Emulation and ONCE™ Mode Support for QFP and PLCC Packages
- Windowed Human Interface with Mouse Support
- Source Level Debug with effective Source Window and Watch Window Operations
- Powerful Go Command with two-level breakpoints, event counters and single stepping capability
- High-Level Language Symbolic Debug
- Tutorial Software to Speed Up Learning Curve
- Complete Intel Service and Support

* Available in Q1 '91

November 1990
Order Number: 280897-002

FEATURES

RELIABLE HIGH SPEED EMULATION

The ICE-186EB/188EB emulator uses superior Intel component bondout and advanced cable technology to ensure accuracy of emulation. Accurate timing is a critical factor in today's 16 MHz designs.

The emulator is designed to support low power application needs. The probe supports true CMOS voltage inputs/outputs and has low power current draw. There is no power consumption difference between using the emulator or the actual component. The ICE-186EB/188EB also supports the debugging of target systems with 80C187 numeric coprocessor.

WINDOWED HUMAN INTERFACE

The windowed interface increases productivity for both expert and casual users. Multiple windows can simultaneously provide source code, watch variables, memory, registers and trace information. Breakpoints can be set directly on the source code. The source window is automatically updated when the emulator completes a breakpoint or a single stepping operation. The user can program the watch windows to track up to ten program variables. The data displayed in the windows is automatically updated while executing and debugging code. Pull down menus offer a set of common emulator commands, making it easier to configure the debug environment.

PRODUCTIVE EVENT MONITOR CAPABILITY

With higher integration of the GO command, event recognition, and emulator action, complex logic debug is easy and efficient. Breakpoint events can be detected on execution addresses and/or bus addresses and/or bus access types such as memory or I/O reads or writes. Address and data specification can be based on single value, range and don't cares. A flexible single step command allows the user to execute one machine-level or one high-level instruction at a time.

All the emulator commands can be programmed with a set of macro commands and can be included in a procedure for repeated debug sessions. The combined use of the event monitor and the macro programming feature can speed up the application debug. This is also a useful tool for automated manufacturing testing and debug.

PROBLEM TRACKING THROUGH DYNAMIC TRACE BUFFER

The emulator can display up to 3,072 frames of processor activity, including both the execution and data bus activity. The information collected in real time provides valuable reference for tracking down problems. Users can view the trace buffer or modify the trace conditions at any time without stopping the emulation. The trace buffer can be displayed in either instruction or the cycle mode.

SOFTWARE DEBUG WITHOUT A PROTOTYPE

Software developers often are required to debug application code before the functional prototypes are available. The Crystal Power Accessory (CPA) with the emulator map memory provides a complete target environment for debugging software modules that do not require timer and hardware interrupt support. The CPA is also used to run the emulator confidence tests.

The ICE-186EB/188EB provides up to 1 MB of zero wait-state memory. This memory can be used instead of target memory for code debugging. It is addressable in 32 Kbyte increments. The emulator can also be used to support simulated I/O ports, addressable in 4 Kbyte increments.

INTEGRATED HIGH LEVEL LANGUAGE SUPPORT

The ICE-186EB/188EB emulator is designed to support all INTEL software products. Intel's comprehensive language development tools include assembler, ANSI C, PL/M, PASCAL and FORTRAN compilers. These software tools were designed to take advantage of the component architecture and specifically support embedded applications. Symbols from the source code can be directly used in your ICE debug sessions. The ICE source window can display the source code in the original language used to produce the object code. This integrated emulator and language development environment allows designers to focus on the development process.

FEATURES

FAST BREAK SUPPORT

The fastbreak feature is used when there is a need to interrogate the current execution status without halting the emulator for extended periods of time. The fastbreak has a maximum break period of 5625 clock cycles. The requested information can be stored in the trace buffer for later reference.

PRESERVE DRAM CONTENTS

The ICE-186EB/188EB continues DRAM refresh signals even when the emulator has been halted, thus ensuring DRAM memory is not lost or corrupted. During the interrogation mode the emulator will keep the timer functioning and will correctly respond to interrupts in real-time.

MULTIPLE HIGH SPEED COMMUNICATION LINKS

Two communication links are available for use in conjunction with the IBM PC AT host. The emulator can use an RS-232-C serial link with a transfer rate up to 57.6 Kbyte per second. A user supplied National Instruments (IEEE-488) GPIB communication board will provide parallel transfers at rates up to 300 Kbytes per second.

SOFTWARE PERFORMANCE ANALYSIS

Intel's Performance Analysis Tool (iPAT) is designed to increase the team productivity with features such as interrupt latency measurement, code coverage analysis and software module timing analysis. The emulator provides an external connector for the iPAT tool. These features enable the user to design reliable, high performance embedded control products.

BUILT-IN SUPPORT FOR LOGIC ANALYZERS

General purpose logic analyzers can be used with the ICE-186EB/188EB emulator to provide detailed timing of specific events. The emulator has an external sync signal to trigger the logic analyzer, making complex event triggering easy. An additional 60 pin connector is included to support the logic analyzer.

SOFTWARE CAROUSEL

To address the need of switching among different development tools, such as editing, recompilation and linking with minimum interruptions, the Software Carousel package is included. It provides an environment which allows up to eleven other programs to be accessible while running the emulator software. By pressing a pair of keys, the current program environment is preserved and a different application environment is ready.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops. In addition, on-site consulting services, field application engineering expertise, telephone hotline support and software and hardware maintenance contracts are available to help assure your design success, as well as electronic bulletin boards and other services.

SPECIFICATIONS

PERSONAL COMPUTER REQUIREMENTS

The ICE-186EB/188EB emulator is hosted on an IBM PC AT platform or IBM PS/2. The emulator has been tested and evaluated on an IBM PC AT. The PC AT must meet the following minimum requirements:

- 640 KBytes of Memory
- An additional 1 MBytes of expanded memory, recommending an Above Board managed by emm.sys driver. Other memory managers conforming to the Lotus/Intel/Microsoft Expanded Memory Specification Version 3.2 or later are available.
- One 20 MBytes Hard Disk
- PC DOS 3.2 or Later
- A serial Port (COM1 or COM2) supporting minimally at 9600 Baud Data Transfers, or a National Instruments GPIB-PC2A board
- Math coprocessor

SPECIFICATIONS

PHYSICAL DESCRIPTION AND CHARACTERISTICS

The ICE-186EB/188EB Emulator consists of the following components:

Table 1 Emulator's Physical Characteristics

Unit	Width		Height		Length	
	In.	Cm	In.	Cm	In.	Cm
Emulator Control Unit	10.4	26.4	1.7	4.3	20.7	52.6
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Probe	3.7	9.4	.65	1.6	7.0	17.8
User Probe Adapter Cable					3.4	8.6
Crystal Power Accessory	4.30	10.9	.60	1.5	6.7	17.0
Serial Cable					144.0	366.0

ICE™-186EB/188EB AC SPECIFICATIONS

Table 2 ICE™-186EB/188EB AC Specifications

Timing Requirements			
Symbol	Parameter	Component Min	Component Max	ICE Typical
T_{DVCL}	Data in Setup (A/D)	10nS		19nS
T_{CLDX}	Data in Hold (A/D)	0		−2
T_{SRYCL}	Synchronous Ready (READY) Transition Setup Time	10		10
T_{CLSRY}	READY Transition Hold Time	0		0
T_{HVCL}	HOLD Setup	10		24
T_{CLHV}	HOLD Hold	0		0
T_{INVCH}	NMI TEST #	10		15
	INTR, TIMERIN Setup Time	10		10
T_{CHINV}	NMI TEST #	0		0
	INTR, TIMERIN Hold Time	0		0

SPECIFICATIONS

ICE™-186EB/188EB AC SPECIFICATIONS

Table 2 (Continued)

Output Delays					
Symbol	**Parameter**	**CPU**		**Emulator**	
		Min	**Max**	**Min**	**Max**
T_{CHOV1}	ALE, S2:0#, DEN#, DT/R#	3nS	20nS	3nS	20nS
T_{CHOV2}	GCS7:0#, LCS#, UCS#, NCS#	3	25	3	25
T_{CLOV1}	BHE#, DEN#, LOCK#, RESOUT, HLDA T0OUT, T1OUT A19:16	3	20	3	20
T_{CLOV2}	RD#, WR#, GCS7:0#, LCS#, UCS#, NCS#, INTA1:0#	3	25	3	25
T_{CLADV}	AD15:0	3	25	6	34
T_{CHOF}	RD#, WR#, BHE#, DT/R#, LOCK#, S2:0#, A19:16	0	25	0	25
T_{CLOF}	DEN#	0	25	0	25
T_{CLADF}	AD15:0	0	25	3	34
Clkin Requirements					
Symbol	**Parameter**	**CPU**		**Emulator**	
		Min	**Max**	**Min**	**Max**
T_C	CLKIN Period	31.25nS	∞	31.25nS	∞*
T_{CKHL}	CLKIN Fall Time	0	8	0	8
T_{CKLH}	CLKIN Rise Time	0	8	0	8
T_{CLCK}	CLKIN Low Time	20	∞	20	∞*
T_{CHCK}	CLKIN High Time	20	∞	20	∞*
Clkout Timing					
T_{CICO}	CLKIN to CLKOUT Skew	0nS	15nS	0nS	15nS
T_{CLCL}	CLKOUT Period	$2*T_C$		$2*T_C$	
T_{CLCH}	CLKOUT Low Time	(T/2)−5	(T/2)+5	(T/2)−5	(T/2)+5
T_{CHCL}	CLKOUT High Time	(T/2)−5	(T/2)+5	(T/2)−5	(T/2)+5
T_{CH1CH2}	CLKOUT Rise Time	1	6	1	6
T_{CL2CL1}	CLKOUT Fall Time	1	6	1	6

*Emulator will acknowledge condition with a "clock lost" error message

SPECIFICATIONS

ICE™-186EB/188EB DC SPECIFICATIONS

Table 3 lists the DC input specifications at the ICE-186EB user probe.

Table 3 ICE™-186EB/188EB DC Input Specifications

Parameter	Signals	CPU		Emulator	
		Max	Min	Max	Min
V_{IL}	All (except CLKIN, HOLD, RESIN$4# and NMI)	.3*V_{CC}	−.5	.3*V_{CC}	−.5
V_{IL}	HOLD, RESIN# and NMI	.3*V_{CC}	−.5	.8	−.5
V_{IL}	CLKIN	.2*V_{CC}	−.3	.2*V_{CC}	−.3
V_{IH}	All (except CLKIN, HOLD, RESIN# and NMI)	V_{CC}+.5	.7*V_{CC}	V_{CC}+.5	.7*V_{CC}
V_{IH}	HOLD, RESIN# and NMI	V_{CC}+.5	.7*V_{CC}	7.0	2.0
V_{IH}	CLKIN	V_{CC}+.3	.8*V_{CC}	V_{CC}+.3	.8*V_{CC}
I_{IL}	All (except HOLD, RESIN#, NMI, A19:16 and LOCK#)	±15uA		±15uA	
I_{IL}	HOLD, RESIN#, NMI	±15uA		−.6mA	
I_{IL}	A19:16 and LOCK#	−2mA		−2mA	

Table 4 lists the DC output specifications at the ICE-186EB user probe.

Table 4 ICE™-186EB/188EB DC Output Specifications

Parameter	Signals	CPU		Emulator	
		Max	Min	Max	Min
V_{OH}	All (except AD15:0)		V_{CC}−.5		V_{CC}−.5
V_{OH}	AD15:0		V_{CC}−.5		3.94
V_{OL}	All (except AD15:0)	.45		.45	
V_{OL}	AD15:0	.45		.44	
I_{OH}	All (except AD15:0)	−2mA		−2mA	
I_{OH}	AD15:0	−2mA		−24mA	
I_{OL}	All (except AD15:0)	5mA		5mA	
I_{OL}	AD15:0	5mA		24mA	

intel

SPECIFICATIONS

Table 5 lists the DC specifications for the ISYNCH and OSYNCH lines.

Table 5 DC Specifications for ISYNCH and OSYNCH

Symbol	Parameter	Min	Max	Notes
ISYNCH I_{IL}	Input Low current		2.6mA	Vi = 0.5V
ISYNCH I_{IH}	Input High current		−100uA	Vi = 2.7V
OSYNC V_{OL}	Output Low voltage		0.5V	Ioi = 15mA
OSYNCH V_{OH}	Output High voltage	2.7V	Ioh = −0.25mA	

Table D-6 lists the DC power requirements at the ICE-186EB user probe.

Table 6 Probe Power Specifications

Symbol	Parameter	Min	Max
V_{CC}	Supply Voltage	4.75	5.25
I_{CC}	Supply Current		90mA

2

ORDERING INFORMATION

ICE186EBP	ICE-186EB 16 MHz system, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adaptor and ONCE adaptor
ICE186EBQ	ICE-186EB 16 MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adaptor
ICE188EBP	ICE-188EB 16 MHz System, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adaptor and ONCE adaptor
ICE188EBQ	ICE-188EB 16 MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adaptor

The above order codes must order a memory option

MEM128	128 Kbytes map memory
MEM512	512 Kbytes map memory
MEM1MB	1 Mbytes map memory
D86ASM86KIT	Assembler, Link-86, Loc-86, Lib 86, cross reference utility, OH-86, numerics support, software debugger, hosted on PC DOS 3.0 or higher
D86C86NL	C-86 compiler for PC DOS 3.0 or higher
D86PLM86NL	PL/M-86 compiler for PC DOS 3.0 or higher
D86PAS86NL	PASCAL-86 compiler for PC DOS 3.0 or higher
D86FOR86NL	FORTRAN-86 compiler for PC DOS 3.0 or higher
*D86ASM86NL	ASM-86 Macro Assembler

*European customers only

Table 5 lists the DC specifications for the ISYNCH and OSYNCH lines.

Table 6 DC Specifications for ISYNCH and OSYNCH

Symbol	Parameter	Min	Max	Notes
$ISYNCH\ I_{IL}$	Input Low current		2.6mA	$V_I = 0.5V$
$ISYNCH\ I_{IH}$	Input High current		−100uA	$V_I = 2.7V$
$OSYNC\ V_{OL}$	Output Low voltage		0.5V	$I_{OL} = 16mA$
$OSYNCH\ V_{OH}$	Output High voltage	2.7V	$I_{OH} = -0.25mA$	

Table D-6 lists the DC power requirements at the ICE-186EB user probe.

Table 6 Probe Power Specifications

Symbol	Parameter	Min	Max
V_{CC}	Supply Voltage	4.75	5.25
I_{CC}	Supply Current		80mA

2

ORDERING INFORMATION

ICE186EBP	ICE-186EB 16 MHz system, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adapter and ONCE adapter	MEM128	128 Kbytes map memory
		MEM512	512 Kbytes map memory
		MEM1MB	1 Mbytes map memory
ICE186EBQ	ICE-186EB 16 MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adapter	D86ASM86KIT	Assembler, Link-86, Loc-86, Lib-86, cross reference utility, CHI-86, numerics support, software debugger, hosted on PC DOS 3.0 or higher
		D86CMENL	C-86 compiler for PC DOS 3.0 or higher
ICE186EBP	ICE-186EB 16 MHz System, includes control unit, PLCC probe, power supply, emulator s/w, Software Carousel, CPA adapter and ONCE adapter	D86PLM86NL	PL/M-86 compiler for PC DOS 3.0 or higher
		D86PAS86NL	PASCAL-86 compiler for PC DOS 3.0 or higher
ICE186EBQ	ICE-186EB 16 MHz system, includes control unit, QFP probe, power supply, emulator s/w, Software Carousel, CPA adapter	D86FOR86NL	FORTRAN-86 compiler for PC DOS 3.0 or higher
		*D86ASM86NL	ASM-86 Macro Assembler

*European customers only

The above order codes must order a memory option

80960KA/KB Product Overview and Data Sheets

3

3 80960KA/KB Product Overview and Data Sheets

80960KA-KB PRODUCT OVERVIEW

INTRODUCTION

This chapter provides an overview of the Intel 80960KB processor (which is part of the 80960K series of embedded-processor products).

All of the processors in the 80960K series of products are based on the Intel 80960 architecture. Most of the information in this overview also applies to the 80960KA processor. The only difference between the 80960KB and 80960KA processors is that the 80960KA does not provide on-chip support for floating-point operations or operations on decimal numbers.

OVERVIEW OF THE 80960KB ARCHITECTURE

The 80960KB processor introduced the 80960 architecture – a new 32-bit architecture from Intel. This architecture has been designed to meet the needs of embedded applications such as machine control, robotics, process control, avionics, and instrumentation.

The 80960 architecture can best be characterized as a high-performance computing engine. It features high-speed instruction execution and ease of programming. It is also easily extensible, allowing processors and controllers based on this architecture to be conveniently customized to meet the needs of specific processing and control applications.

The following are some of the important attributes of the 80960 architecture:

- Full 32-bit registers
- High-speed, pipelined instruction execution
- A convenient program execution environment with 32 general-purpose registers and a versatile set of special-function registers
- A highly optimized procedure call mechanism that features on-chip caching of local variables and parameters
- Extensive facilities for handling interrupts and faults
- Extensive tracing facilities to support efficient program debugging and monitoring
- Register scoreboarding and write buffering to permit efficient operation when used with lower performance memory subsystems.

OVERVIEW OF THE SINGLE PROCESSOR SYSTEM ARCHITECTURE

The central processing module, memory module, and I/O module form the natural boundaries for the hardware system architecture. The modules are connected together by the high bandwidth 32-bit multiplexed L-bus, which can transfer data at a maximum sustained rate of 53M bytes per second for an 80960 processor operating at 20 MHz.

Figure 1 shows a simplified block diagram of one possible system configuration. The heart of this system is the 80960KB processor, which fetches instructions, executes code, manipulates stored information, and interacts with I/O devices. The high bandwidth L-bus connects the 80960KB processor to memory and I/O modules. The 80960KB processor stores system data, instructions, and programs in the memory module. By accessing various peripheral devices in the I/O module, the 80960KB processor supports communication to terminals, modems, printers, disks, and other I/O devices.

80960KB Processor and the L-Bus

The 80960KB processor performs bus operations using multiplexed address and data signals, and provides all the necessary control signals. For example, standard control signals, such as Address Latch Enable ($\overline{ALE}$), Address/Data Status ($\overline{ADS}$), Write/Read Command (W/$\overline{R}$), Data Transmit/Receive (DT/$\overline{R}$), and Data Enable ($\overline{DEN}$), are provided by the 80960KB processor. The 80960 processor also generates byte enable signals that specify which bytes on the 32-bit data lines are valid for the transfer.

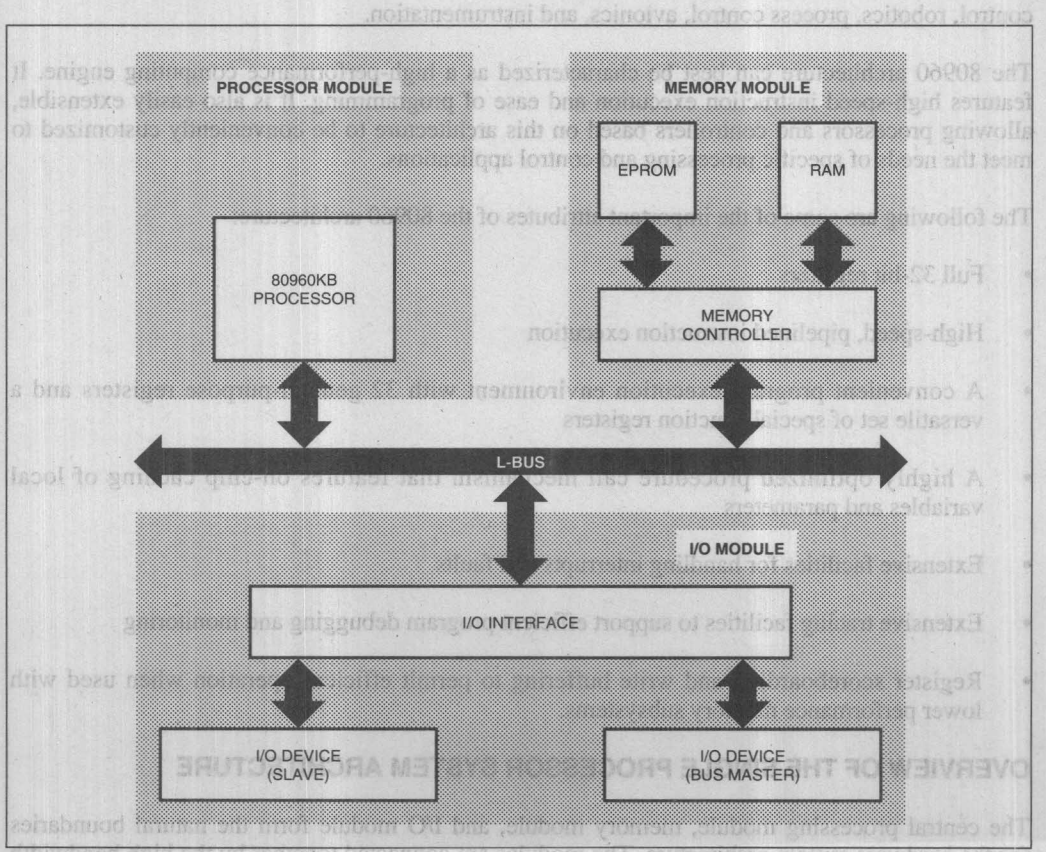


Figure 1. Basic 80960MC System Configuration

The L-bus supports burst transactions, which access up to four data words at a maximum rate of one word per clock cycle. The 80960KB processor uses the two low-order address lines to indicate how many words are to be transferred. The 80960KB processor performs burst transactions to load the on-chip 512-byte instruction cache to minimize memory accesses for instruction fetches. Burst transactions can also be used for data access.

To transfer control of the bus to an external bus master, the 80960KB provides two arbitration signals: hold request (HOLD) and hold acknowledge (HLDA). After receiving HOLD, the processor grants control of the bus to an external master by asserting HLDA.

The 80960KB processor provides a flexible interrupt structure by using an on-chip interrupt controller, an external interrupt controller, or both. The type of interrupt structure is specified by an internal interrupt vector register. For a system with multiple processors, another method is available, called inter-agent communication (IAC) where a processor can interrupt another processor by sending an IAC message.

Memory Module

A memory module can consist of a memory controller, Erasable Programmable Read Only Memory (EPROM), and static or dynamic Random Access Memory (RAM). The memory controller first conditions the L-bus signals for memory operation. It demultiplexes the address and data lines, generates the chip select signals from the address, detects the start of the cycle for burst mode operation, and latches the byte enable signals.

The memory controller generates the control signals for EPROM, SRAM. and DRAM. Specifically, it provides the control signals, multiplexed row/column address, and refresh control for dynamic RAMs. The controller can be designed to accommodate the burst transaction of the 80960KB processor by using the static column mode or nibble mode features of the dynamic RAM. In addition to supplying the operational signals, the controller generates the READY signal to indicate that data can be transferred to or from the 80960KB processor.

The 80960KB processor directly addresses up to 4G bytes of physical memory. The processor does not allow burst accesses to cross a 16-byte boundary, to ease the design of the controller. Each address specifies a four-byte data word within the block. Individual data bytes can be accessed by using the four byte-enable signals from the 80960KB processor. Chapter 5 provides design guidelines for the memory controller.

I/O Module

The I/O module consists of the I/O components and the interface circuit. I/O components can be used to allow the 80960KB processor to use most of its clock cycles for computational and system management activities. Time consuming tasks can be off-loaded to specialized slave-type components, such as the 8259A Programmable Interrupt Controller or the 82530 Serial Communication Controller. Some tasks may require a master-type component, such as the 82586 Local Area Network Control .

The interface circuit performs several functions. It demultiplexes the address and data lines, generates the chip select signals from the address, produces the I/O read or I/O write command from the processor's W/R signal, latches the byte enable signals, and generates the READY signals. Since some of these functions are identical to those of the memory controller, the same logic can be used for both interfaces. For master-type peripherals that operate on a 16-bit data bus, the interface circuit translates the 32-bit data bus to a 16-bit data bus.

The 80960KB processor uses memory-mapped addresses to access I/O devices. This allows the CPU to use many of the same instructions to exchange information for both memory and peripheral devices. Thus, the powerful memory-type instructions can be used to perform 8-, 16-, and 32-bit data transfers.

HIGH PERFORMANCE PROGRAM EXECUTION

Much of the design of the 80960 architecture has been aimed at maximizing the processor's computational and data processing speed through the use of increased parallelism. The following paragraphs describe several of the mechanisms and techniques used to accomplish this goal.

Load and Store Model

One of the more important features of the 80960 architecture is its performance of most operations on operands in registers, rather than in memory. For example, all arithmetic, logic, comparison, branching and bit operations are performed with registers and literals.

This feature provides two benefits. First, it increases program execution speed by minimizing the number of memory accesses necessary to execute a program. Second, it reduces the memory latency encountered when using slower, lower-cost memory parts.

To support this concept, the architecture provides a generous supply of general-purpose registers. For each procedure, 32 registers are available, 28 of which are available for general use. These registers are divided into two types: global and local. Both types of registers can be used for general storage of operands. The only difference is that global registers retain their contents across procedure boundaries, whereas the processor allocates a new set of local registers each time a new procedure is called.

The architecture also provides a set of fast, versatile load and store instructions. These instructions allow burst transfers of 1, 2, 4, 8, 12, or 16 bytes of information between memory and the registers.

On-Chip Caching of Code and Data

To further reduce memory accesses, the architecture offers two mechanisms for caching code and data on chip: an instruction cache and multiple sets of local registers. The instruction cache allows prefetching of blocks of instruction from memory. This helps ensure that the instruction execution pipeline is supplied with a steady stream of instructions. It also reduces the number of

memory accesses required when performing iterative operations such as loops. The architecture allows the size of the instruction cache to vary. For the 80960KB processor, it is 512 bytes.

To optimize the architecture's procedure call mechanism, the processor provides multiple sets of local registers. This allows the processor to perform procedure calls without having to write the local registers out to the stack in memory. The number of register sets depends on the processor implementation. The 80960KB processor provides four sets of local registers.

Overlapped Instruction Execution

The 80960 architecture also enhances program execution speed by overlapping the execution of some instructions. In the 80960K series of processors, this is accomplished through register scoreboarding.

Register scoreboarding permits instruction execution to continue while data is being fetched from memory. When a load instruction is executed, the processor sets one or more scoreboard bits to indicate the target registers to be loaded. After the target registers are loaded, the scoreboard bits are cleared. While the target registers are being loaded, the processor is allowed to execute other instructions that do not use these registers.

The processor uses the scoreboard bits to ensure that the target registers are not used until the load is complete. (Scoreboard bits are checked transparently from software.) This technique allows code to be executed such that some instructions can be executed in zero clock cycles (that is, executed for free).

Single-Clock Instructions

The 80960 architecture is designed to let a processor execute commonly used instructions, such as moves, adds, subtracts, logical operations, and branches, in a minimum number of clock cycles (preferably one cycle). The architecture supports this concept in several ways. For example, the load and store model described earlier eliminates the clock cycles required to perform memory-to-memory operations, by concentrating on register-to-register operations.

In addition, all of the instructions in the 80960 architecture are 32 bits long and aligned on 32-bit boundaries. This lets instructions be decoded in one clock cycle, and eliminates the need for an instruction-alignment stage in the pipeline.

The 80960KB processor takes full advantage of these features of the architecture, resulting in more than 50 instructions that can be executed in a single clock cycle.

Efficient Interrupt Model

The 80960 architecture provides an efficient mechanism for servicing interrupts from external sources. To handle interrupts, the processor maintains an interrupt table of 248 interrupt vectors, 240 of which are available for general use. When an interrupt is signaled, the processor uses a

pointer to the interrupt table to perform an implicit call to an interrupt handler procedure. In performing this call, the processor automatically saves the state of the processor prior to receiving the interrupt, performs the interrupt routine, then restores the state of the processor. A separate interrupt stack is also provided to segregate interrupt handling from application programs.

The interrupt handling facilities also allow interrupts to be evaluated by priority. The processor is then able to store interrupt vectors that are lower in priority than the current processor task in a pending interrupt section of the interrupt table. The processor checks and services the pending interrupts at defined times.

SIMPLIFIED PROGRAMMING ENVIRONMENT

Because of its streamlined execution environment, processors based on the 80960 architecture are particularly easy to program. The following paragraphs describe some of the architecture features that simplify programming.

Highly Efficient Procedure Call Mechanism

The procedure call mechanism makes procedure calls and parameter passing between procedures simple and compact. Each time a call instruction is issued, the processor automatically saves the current set of local registers and allocates a new set for the called procedure. Likewise, on a return from a procedure, the current set of local registers is deallocated and the local registers for the procedure being returned to are restored. This means a program never has to explicitly save and restore those local variables that are stored in local registers.

Versatile Instruction Set and Addressing

The selection of instructions and addressing modes also simplifies programming. A full set of load, store, move, arithmetic, comparison, and branch instructions are provided, with operations on both integer and ordinal data types. Operations on bits and bit strings are simplified by a complete set of Boolean and bit-field instructions.

The addressing modes are efficient and straightforward, while at the same time providing the necessary indexing and scaling modes required to address complex arrays and record structures. The large 4-gigabyte address space provides ample room to store programs and data. The availability of 32 addressing lines allows some address lines to be memory-mapped to control hardware functions.

Extensive Fault Handling Capability

To aid in program development, the 80960 architecture defines a wide range of faults that the processor detects, including arithmetic faults, invalid operations, invalid operands, and machine faults. When a fault is detected, the processor makes an implicit call to a fault handler routine, in

a way similar to the interrupt mechanism described previously. The information collected for each fault allows program developers to quickly correct faulting code, and allows automatic recovery from some faults.

Debugging and Monitoring

To support debugging systems, the 80960 architecture provides a mechanism for monitoring processor activity by means of trace events. When the processor detects a trace event, it signals a trace fault and calls a fault handler. Intel provides several tools that use this feature, including an in-circuit emulator (ICE) device.

SUPPORT FOR ARCHITECTURAL EXTENSIONS

The 80960 architecture provides several features that enable processors based on this architecture to be easily customized to meet the needs of specific embedded applications, such as signal processing, array processing, or graphics processing.

The most important of these features is the set of 32 special function registers. These registers provide a convenient interface to circuitry in the processor or pins that can be connected to external hardware. They can be used to control timers, to perform operations on special data types, or to perform I/O functions. The special function registers are similar to the global registers. They can be addressed by all of the register access instructions.

EXTENSIONS INCLUDED IN THE 80960K SERIES PROCESSORS

The 80960K series of processors provides a complete implementation of the 80960 architecture, plus several extensions to that architecture. These extensions fall into two categories: floating-point processing and inter-agent communication.

On-Chip Floating Point

The 80960KB processor provides a complete implementation of the IEEE standard for binary floating-point arithmetic (IEEE 754-185). This implementation includes a full set of floating-point operations, including add, subtract, multiply, divide, trigonometric functions, and logarithmic functions. These operations are performed on single precision (32-bit), double precision (64-bit), and extended precision (80-bit) real numbers.

One of the benefits of this implementation is that the floating-point handling facilities are integrated into the normal instruction execution environment. Single and double precision floating-point values are stored in the same registers as non-floating point values. Four 80-bit floating-point registers are provided to hold extended-precision values.

Interagent Communication

All of the processors in the 80960K series provide an inter-agent communication (IAC) mechanism, allowing agents connected to the processor's bus to communicate with one another. This mechanism operates similarly to the interrupt mechanism, except that IAC messages are passed through dedicated sections of memory. The sort of tasks handled with IAC messages are processor reinitialization, stopping the processor, purging the instruction cache, and forcing the processor to check pending interrupts.

80960KA
EMBEDDED 32-BIT PROCESSOR

- **High-Performance Embedded Architecture**
  - **25 MIPS Burst Execution at 25 MHz**
  - **9.4 MIPS* Sustained Execution at 25 MHz**
- **512-Byte On-Chip Instruction Cache**
  - **Direct Mapped**
  - **Parallel Load/Decode for Uncached Instructions**
- **Pin Compatible with 80960KB**
- **Multiple Register Sets**
  - **Sixteen Global 32-Bit Registers**
  - **Sixteen Local 32-Bit Registers**
  - **Four Local Register Sets Stored On-Chip**
  - **Register Scoreboarding**
- **Built-In Interrupt Controller**
  - **32 Priority Levels 256 Vectors**
  - **Supports 8259A**
  - **3.4 μs Latency @ 25 MHz**
- **Easy to Use, High Bandwidth 32-Bit Bus**
  - **66.7 MBytes/s Burst**
  - **Up to 16-Bytes Transferred per Burst**
- **4 Gigabyte, Linear Address Space**
- **132-Lead Pin Grid Array (PGA) Package**
- **132-Lead Plastic Quad Flat Pack (PQFP)**
- **Uses 85C960 Bus Controller**
- **Supported by 27960KX Burst EPROMs**

3

The 80960KA is a member of Intel's new 32-bit processor family, the i960 series, which is designed especially for embedded applications. It is based on the family's high performance, common core architecture, and includes a 512-byte instruction cache and a built-in interrupt controller. The 80960KA has a large register set, multiple parallel execution units, and a high-bandwidth, burst bus. Using advanced RISC technology, this high performance processor is capable of execution rates in excess of 9.4 million instructions per second.* The 80960KA is well-suited for a wide range of embedded applications, including laser printers, image processing, industrial control, robotics, and telecommunications.

*Relative to Digital Equipment Corporation's VAX-11/780** at 1 MIPS

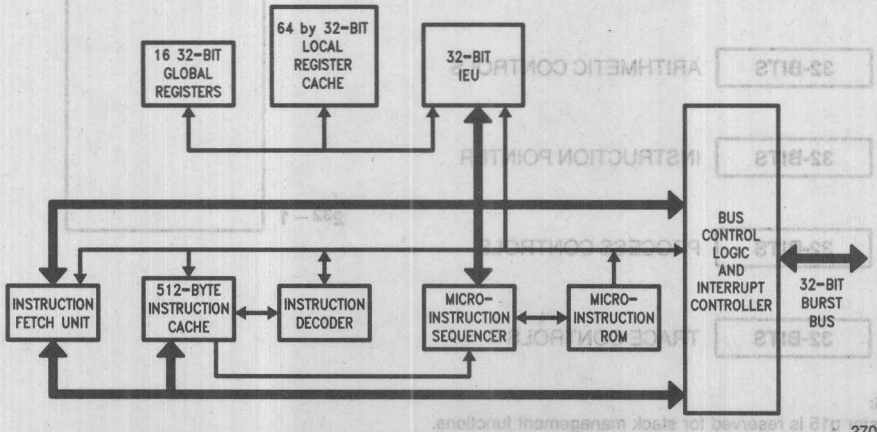


Figure 1. The 80960KA's Highly Parallel Microarchitecture

**VAX-11™ is a trademark of Digital Equipment Corporation.

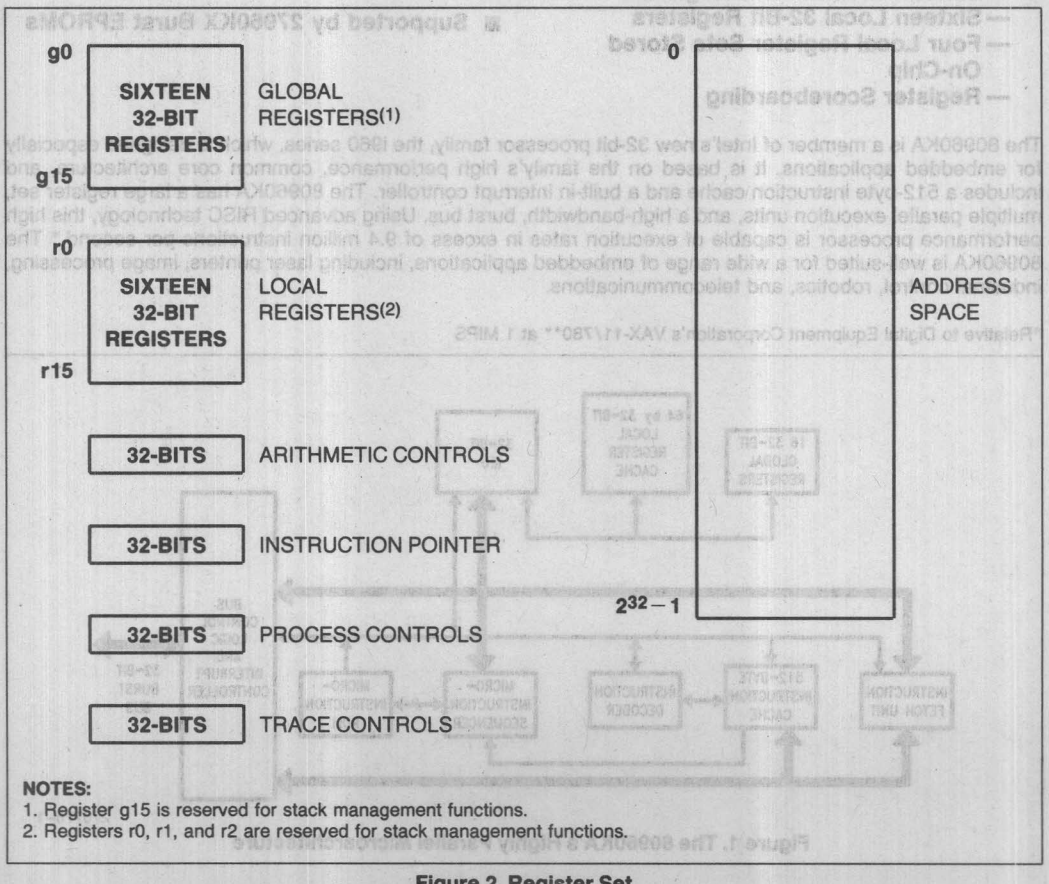
November 1990
Order Number: 270775-003

THE 960 SERIES

The 80960KA is a member of a new family of 32-bit microprocessors from Intel known as the i960 Series. This series was especially designed to serve the needs of embedded applications. The embedded market includes applications as diverse as industrial automation, avionics, image processing, graphics, robotics, telecommunications, and automobiles. These types of applications require high integration, low power consumption, quick interrupt response times, and high performance. Since time to market is critical, embedded microprocessors need to be easy to use in both hardware and software designs.

All members of the 80960 series share a common core architecture which utilizes RISC technology so that, except for special functions, the family members are object code compatible. Each new processor in the series will add its own special set of functions to the core to satisfy the needs of a specific application or range of applications in the embedded market. For example, future processors may include a DMA controller, a timer, or an A/D converter.

Software written for the 80960KA will run without modification on any other member of the 80960 family. It is also pin-compatible with the 80960KB, which includes an integrated floating-point unit, and the 80960MC, a military-grade version with support for multitasking, memory management, multiprocessing, and fault tolerance.



NOTES:
1. Register g15 is reserved for stack management functions.
2. Registers r0, r1, and r2 are reserved for stack management functions.

Figure 2. Register Set

KEY PERFORMANCE FEATURES

The 80960KA's architecture is based on the most recent advances in RISC technology and is grounded in Intel's long experience in designing embedded controllers. Many features contribute to the 80960KA's exceptional performance:

1. Large Register Set. Modern compilers can take advantage of a large number of registers to optimize execution speed. For maximum flexibility, the 80960KA provides 32 32-bit registers and four 80-bit floating-point registers. (See Figure 2.)

2. Fast Instruction Execution. Simple functions make up the bulk of instructions in most programs, so that execution speed can be greatly improved by ensuring that these core instructions execute in as short a time as possible. The most-frequently executed instructions such as register-register moves, add/subtract, logical operations, and shifts execute in one to two cycles (Table 1 contains a list of instructions.)

3. Load/Store Architecture. One way to improve execution speed is to reduce the number of times that the processor must access memory to perform an operation. Like other processors based on RISC technology, the 80960KA has a Load/Store architecture, only the LOAD and STORE instructions reference memory; all other instructions operate on registers.

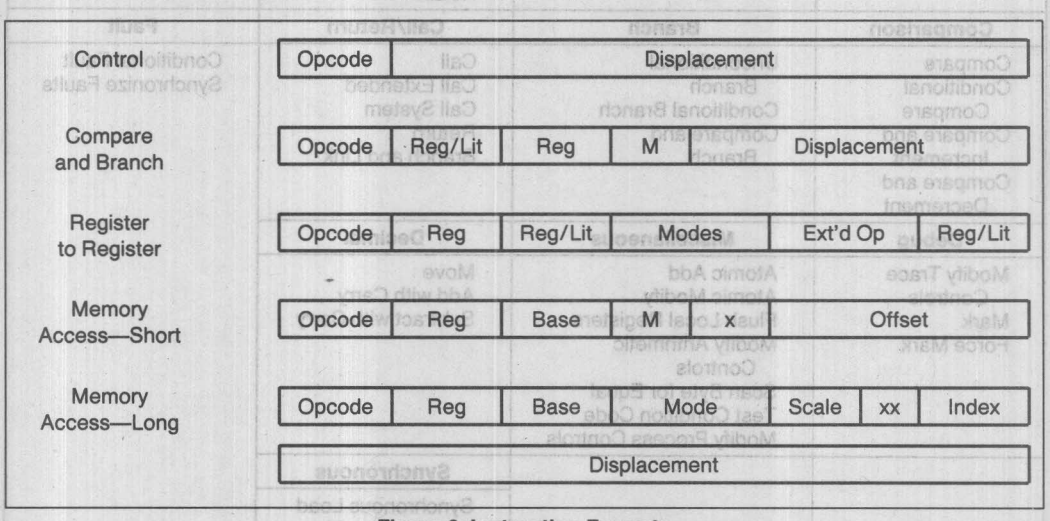


Figure 3. Instruction Formats

Table 1. 80960KA Instruction Set

Data Movement	Arithmetic	Logical	Bit and Bit Field
Load Store Move Load Address	Add Subtract Multiply Divide Remainder Modulo Shift	And Not And And Not Or Exclusive Or Not Or Or Not Nor Exclusive Nor Not Nand Rotate	Set Bit Clear Bit Not Bit Check Bit Alter Bit Scan for Bit Scan over Bit Extract Modify
Comparison	**Branch**	**Call/Return**	**Fault**
Compare Conditional Compare Compare and Increment Compare and Decrement	Unconditional Branch Conditional Branch Compare and Branch	Call Call Extended Call System Return Branch and Link	Conditional Fault Synchronize Faults
Debug	**Miscellaneous**	**Decimal**	
Modify Trace Controls Mark Force Mark	Atomic Add Atomic Modify Flush Local Registers Modify Arithmetic Controls Scan Byte for Equal Test Condition Code Modify Process Controls	Move Add with Carry Subtract with Carry	
		Synchronous	
		Synchronous Load Synchronous Move	

4. Simple Instruction Formats. All instructions in the 80960KA are 32-bits long and must be aligned on word boundaries. This alignment makes it possible to eliminate the instruction-alignment stage in the pipeline. To simplify the instruction decoder further, there are only five instruction formats and each instruction uses only one format. (See Figure 3.)

5. Overlapped Instruction Execution. A load operation allows execution of subsequent instructions to continue before the data has been returned from memory, so that these instructions can overlap the load. The 80960KA manages this process transparently to software through the use of a register scoreboard. Conditional instructions also make use of a scoreboard so that subsequent unrelated instructions can be executed while the conditional instruction is pending.

6. Integer Execution Optimization. When the result of an operation is used as an operand in a subsequent calculation, the value is sent immediately to its destination register. Yet at the same time, the value is put back on a bypass path to the ALU, thereby saving the time that otherwise would be required to retrieve the value for the next operation.

7. Bandwidth Optimizations. The 80960KA gets optimal use of its memory bus bandwidth because the bus is tuned for use with the cache: the line size of the instruction cache matches the maximum burst size for instruction fetches. The 80960KA automatically fetches four words in a burst and stores them directly in the cache. Due to the size of the cache and the fact that it is continually filled in anticipation of needed instructions in the program flow, the 80960KA is exceptionally insensitive to memory wait states. In fact, each wait state causes only a 7% degradation in system perfomance. The benefit is that the 80960KA will deliver outstanding performance even with a low cost memory system.

8. Cache Bypass. If there is a cache miss, the processor fetches the needed instruction, then sends it on to the instruction decoder at the same time it updates the cache. Thus, no extra time is taken to load and read the cache.

Memory Space and Addressing Modes

The 80960KA offers a linear programming environment so that all programs running on the processor are contained in a single address space. The maximum size of the address space is 4 Gigabytes (2^{32} bytes).

For ease of use, the 80960KA has a small number of addressing modes, but includes all those necessary to ensure efficient compiler implementations of high-level languages such as C, Fortran and Ada. Table 2 lists the memory addressing modes.

Data Types

The 80960KA recognizes the following data types:

Numeric:
- 8-, 16-, 32- and 64-bit ordinals
- 8-, 16, 32- and 64-bit integers

Non-Numeric:
- Bit
- Bit Field
- Triple-Word (96 bits)
- Quad-Word (128 bits)

Large Register Set

The programming environment of the 80960KA includes a large number of registers. In fact, 32 registers are available at any time. The availability of this many registers greatly reduces the number of memory accesses required to execute most programs, which leads to greater instruction processing speed.

There are two types of general-purpose registers: local and global. The global registers consist of sixteen 32-bit registers (G0 through G15) These registers perform the same function as the general-purpose registers provided in other popular microprocessors. The term global refers to the fact that these registers retain their contents across procedure calls.

The local registers, on the other hand, are procedure specific. For each procedure call, the 80960KA allocates 16 local registers (R0 through R15). Each local register is 32 bits wide.

Multiple Register Sets

To further increase the efficiency of the register set, multiple sets of local registers are stored on-chip. This cache holds up to four local register frames, which means that up to three procedure calls can be made without having to access the procedure stack resident in memory.

Although programs may have procedure calls nested many calls deep, a program typically oscillates back and forth between only two or three levels. As

Table 2. Memory Addressing Modes

- 12-Bit Offset
- 32-Bit Offset
- Register-Indirect
- Register + 12-Bit Offset
- Register + 32-Bit Offset
- Register + (Index-Register × Scale-Factor)
- Register × Scale Factor + 32-Bit Displacement
- Register + (Index-Register × Scale-Factor) + 32-Bit Displacement

Scale-Factor is 1, 2, 4, 8 or 16

a result, with four stack frames in the cache, the probability of there being a free frame on the cache when a call is made is very high. In fact, runs of representative C-language programs show that 80% of the calls are handled without needing to access memory.

If there are four or more active procedures and a new procedure is called, the processor moves the oldest set of local registers in the register cache to a procedure stack in memory to make room for a new set of registers. Global register G15 is used by the processor as the frame pointer (FP) for the procedure stack.

Note that the global registers are not exchanged on a procedure call, but retain their contents, making them available to all procedures for fast parameter passing. An illustration of the register cache is shown in Figure 4.

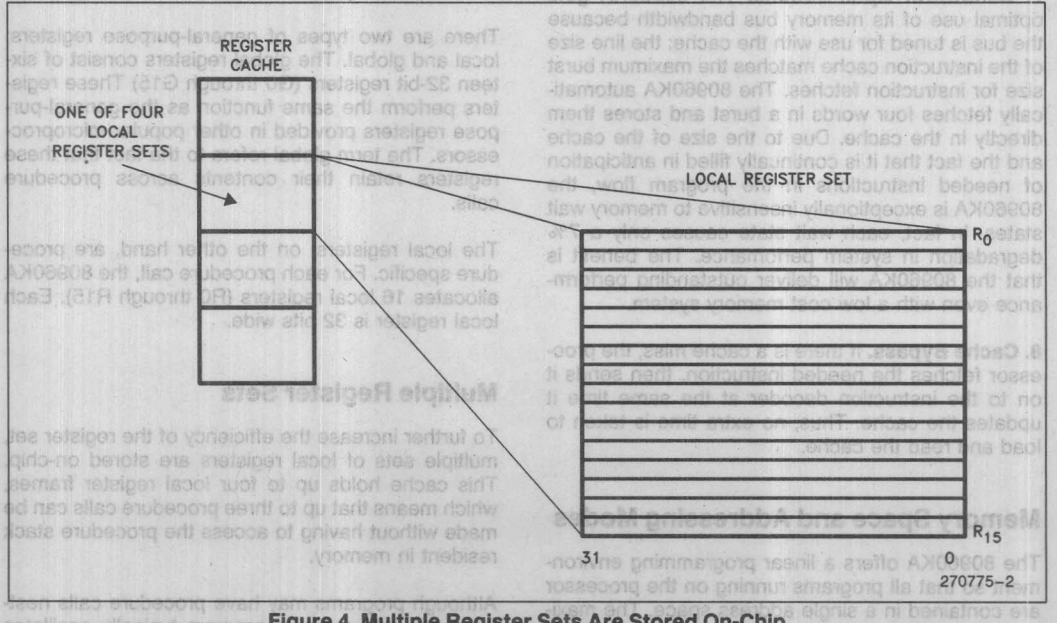


Figure 4. Multiple Register Sets Are Stored On-Chip

Instruction Cache

To further reduce memory accesses, the 80960KA includes a 512-byte on-chip instruction cache. The instruction cache is based on the concept of locality of reference; that is, most programs are not usually executed in a steady stream but consist of many branches and loops that lead to jumping back and forth within the same small section of code. Thus, by maintaining a block of instructions in a cache, the number of memory references required to read instructions into the processor can be greatly reduced.

To load the instruction cache, instructions are fetched in 16-byte blocks, so that up to four instructions can be fetched at one time. An efficient prefetch algorithm increases the probability that an instruction will already be in the cache when it is needed.

Code for small loops will often fit entirely within the cache, leading to a great increase in processing speed since further memory references might not be necessary until the program exits the loop. Similarly, when calling short procedures, the code for the calling procedure is likely to remain in the cache, so it will be there on the procedure's return.

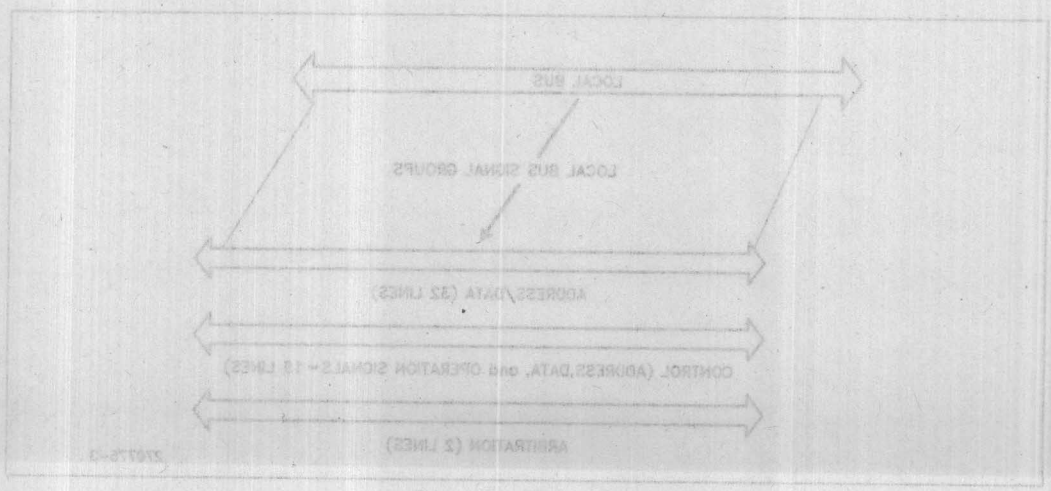
Register Scoreboarding

The instruction decoder has been optimized in several ways. One of these optimizations is the ability to do instruction overlapping by means of register scoreboarding.

Register scoreboarding occurs when a LOAD instruction is executed to move a variable from memory into a register. When the instruction is initiated, a scoreboard bit on the target register is set. When the register is actually loaded, the bit is reset. In between, any reference to the register contents is accompanied by a test of the scoreboard bit to insure that the load has completed before processing continues. Since the processor does not have to wait for the LOAD to be completed, it can go on to execute additional instructions placed in between the LOAD instruction and the instruction that uses the register contents, as shown in the following example:

```
LOAD R4, address 1
LOAD R5, address 2
Unrelated instruction
Unrelated instruction
ADD R4, R5, R6
```

In essence, the two unrelated instructions between the LOAD and ADD instructions are executed for free (i.e., take no apparent time to execute) because they are executed while the register is being loaded. Up to three instructions can be pending at one time with three corresponding scoreboard bits set. By exploiting this feature, system programmers and compilers have a useful tool for optimizing execution speed.



High Bandwidth Local Bus

An 80960KA CPU resides on a high-bandwidth address/data bus known as the local bus (L-Bus). The L-Bus provides a direct communication path between the processor and the memory and I/O subsystem interfaces. The processor uses the local bus to fetch instructions, manipulate memory, and respond to interrupts. Its features include:

- 32-bit multiplexed address/data path
- Four-word burst capability, which allows transfers from 1 to 16 bytes at a time
- High bandwidth reads and writes at 66.7 MBytes per second
- Special signal to indicate whether a memory transaction can be cached

Figure 5 identifies the groups of signals which constitute the L-Bus. Table 4 lists the function of the L-Bus and other processor-support signals, such as the interrupt lines.

Interrupt Handling

The 80960KA can be interrupted in one of two ways: by the activation of one of four interrupt pins or by sending a message on the processor's data bus.

The 80960KA is unusual in that it automatically handles interrupts on a priority basis and tracks pending interrupts through its on-chip interrupt controller. Two of the interrupt pins can be configured to provide 8259A handshaking for expansion beyond four interrupt lines.

Debug Features

The 80960KA has built-in debug capabilities. There are two types of breakpoints and six different trace modes. The debug features are controlled by two internal 32-bit registers, the Process-Controls Word and the Trace-Controls Word. By setting bits in these control words, a software debug monitor can closely control how the processor responds during program execution.

The 80960KA has both hardware and software breakpoints. It provides two hardware breakpoint registers on-chip which can be set by a special command to any value. When the instruction pointer matches the value in one of the breakpoint registers, the breakpoint will fire, and a breakpoint handling routine is called automatically.

The 80960KA also provides software breakpoints through the use of two instructions, MARK and FMARK. These instructions can be placed at any point in a program and will cause the processor to halt execution at that point and call the breakpoint handling routine. The breakpoint mechanism is easy to use and provides a powerful debugging tool.

Tracing is available for instructions (single-step execution), calls and returns, and branching. Each different type of trace may be enabled separately by a special debug instruction. In each case, the 80960KA executes the instruction first and then calls a trace handling routine (usually part of a software debug monitor). Further program execution is halted until the trace routine is completed. When the trace event handling routine is completed, instruction execution resumes at the next instruction. The

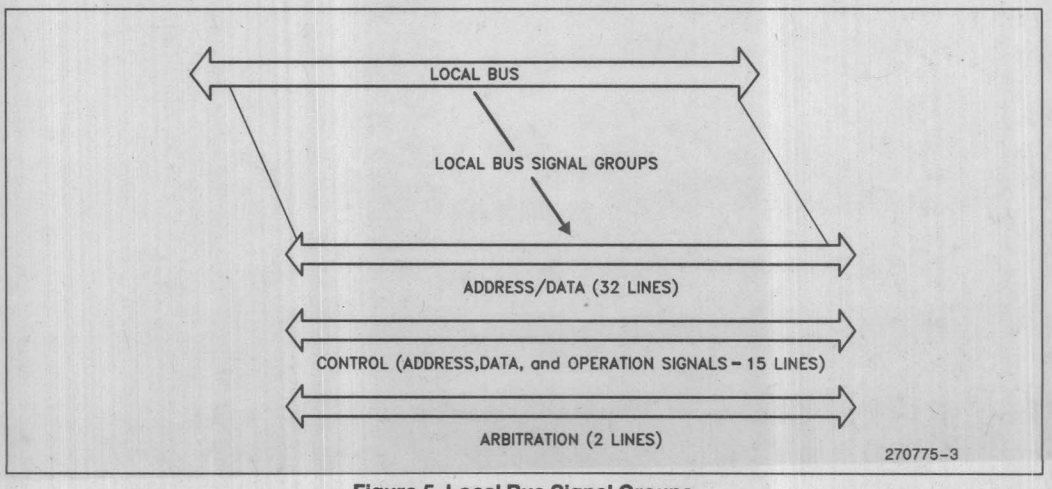


Figure 5. Local Bus Signal Groups

80960KA's tracing mechanisms, which are implemented completely in hardware, greatly simplify the task of testing and debugging software.

FAULT DETECTION

The 80960KA has an automatic mechanism to handle faults. There are ten fault types including trace, arithmetic, and floating-point faults. When the processor detects a fault, it automatically calls the appropriate fault handling routine and saves the current instruction pointer and necessary state information to make efficient recovery possible. The processor posts diagnostic information on the type of fault to a Fault Record. Like interrupt handling routines, fault handling routines are usually written to meet the needs of a specific application and are often included as part of the operating system or kernel.

For each of the ten fault types, there are numerous subtypes that provide specific information about a fault. For example, a floating-point fault may have its subtype set to an Overflow or Zero-Divide fault. The fault handler can use this specific information to respond correctly to the fault.

BUILT-IN TESTABILITY

Upon reset, the 80960KA automatically conducts an extensive internal test (self-test) of its major blocks of logic. Then, before executing its first instruction, it does a zero check sum on the first eight words in memory to ensure that the system has been loaded correctly. If a problem is discovered at any point during the self-test, the 80960KA will assert its FAILURE pin and will not begin program execution. The self-test takes approximately 47,000 cycles to complete.

System manufacturers can use the 80960KA's self-test feature during incoming parts inspection. No special diagnostic programs need to be written, and the test is both thorough and fast. The self-test capability helps ensure that defective parts will be discovered before systems are shipped, and once in the field, the self-test makes it easier to distinguish between problems caused by processor failure and problems resulting from other causes.

CHMOS

The 80960KA is fabricated using Intel's CHMOS IV (Complementary High Speed Metal Oxide Semiconductor) process. This advanced technology eliminates the frequency and reliability limitations of older CMOS processes and opens a new era in microprocessor performance. It combines the high performance capabilities of Intel's industry-leading HMOS technology with the high density and low power characteristics of CMOS. The 80960KA is available at 10, 16, 20 and 25 MHz.

3

Table 4a. 80960KA Pin Description: L-Bus Signals

Symbol	Type	Name and Function
CLK2	I	**SYSTEM CLOCK** provides the fundamental timing for 80960KA systems. It is divided by two inside the 80960KA to generate the internal processor clock.
LAD_{31} $-LAD_0$	I/O T.S.	**LOCAL ADDRESS/DATA BUS** carries 32-bit physical addresses and data to and from memory. During an address (T_a) cycle, bits 2–31 contain a physical word address (bits 0–1 indicate SIZE; see below). During a data (T_d) cycle, bits 0–31 contain read or write data. The LAD lines are active HIGH and float to a high impedance state when not active. **SIZE,** which is comprised of bits 0–1 of the LAD lines during a T_a cycle, specifies the size of a burst transfer in words. LAD_1 / LAD_0: 0 0 = 1 Word; 0 1 = 2 Words; 1 0 = 3 Words; 1 1 = 4 Words
$\overline{ALE}$	O T.S.	**ADDRESS-LATCH ENABLE** indicates the transfer of a physical address. ALE is asserted during a T_a cycle and deasserted before the beginning of the T_d state. It is active LOW and floats to a high impedance state during a hold cycle (T_h or T_{hr}).

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

Table 4a. 80960KA Pin Description: L-Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{ADS}$	O O.D.	**ADDRESS/DATA STATUS** indicates an address state. ADS is asserted every T_a state and deasserted during the following T_d state. For a burst transaction, $\overline{ADS}$ is asserted again every T_d state where $\overline{READY}$ was asserted in the previous cycle.
W/$\overline{R}$	O O.D.	**WRITE/READ** specifies, during a T_a cycle, whether the operation is a write or read. It is latched on-chip and remains valid during T_d cycles.
DT/$\overline{R}$	O O.D.	**DATA TRANSMIT/RECEIVE** indicates the direction of data transfer to and from the L-Bus. It is low during T_a and T_d cycles for a read or interrupt acknowledgement; it is high during T_a and T_d cycles for a write. $\overline{DT/R}$ never changes state when $\overline{DEN}$ is asserted (see Timing Diagrams).
$\overline{DEN}$	O O.D.	**DATA ENABLE** is asserted during T_d cycles and indicates transfer of data on the LAD bus lines.
$\overline{READY}$	I	**READY** indicates that data on LAD lines can be sampled or removed. If $\overline{READY}$ is not asserted during a T_d cycle, the T_d cycle is extended to the next cycle by inserting a wait state (T_W), and $\overline{ADS}$ is not asserted in the next cycle.
$\overline{LOCK}$	I/O O.D.	**BUS LOCK** prevents other bus masters from gaining control of the L-Bus following the current cycle (if they would assert $\overline{LOCK}$ to do so). $\overline{LOCK}$ is used by the processor or any bus agent when it performs indivisible Read/Modify/Write (RMW) operations. Do not leave $\overline{LOCK}$ unconnected. It must be pulled high for the processor to function properly. For a read that is designated as a RMW-read, $\overline{LOCK}$ is examined. if asserted, the processor waits until it is not asserted; if not asserted, the processor asserts $\overline{LOCK}$ during the T_a cycle and leaves it asserted. A write that is designated as an RMW-write deasserts $\overline{LOCK}$ in the T_a cycle. During the time $\overline{LOCK}$ is asserted, a bus agent can perform a normal read or write but no RMW operations. $\overline{LOCK}$ is also held asserted during an interrupt-acknowledge transaction.
$\overline{BE_3}$–$\overline{BE_0}$	O O.D.	**BYTE ENABLE LINES** specify which data bytes (up to four) on the bus take part in the current bus cycle. $\overline{BE_3}$ corresponds to LAD_{31}–LAD_{24} and $\overline{BE_0}$ corresponds to LAD_7–LAD_0. The byte enables are provided in advance of data. The byte enables asserted during T_a specify the bytes of the first data word. The byte enables asserted during T_d specify the bytes of the next data word (if any), that is, the word to be transmitted following the next assertion of $\overline{READY}$. The byte enables during the T_d cycles preceding the last assertion of $\overline{READY}$ are undefined. The byte enables are latched on-chip and remain constant from one T_d cycle to the next when $\overline{READY}$ is not asserted. For reads, the byte enables specify the byte(s) that the processor will actually use. L-Bus agents are required to assert only adjacent byte enables (e.g., asserting just $\overline{BE_0}$ and $\overline{BE_2}$ is not permitted), and are required to assert at least one byte enable. To produce address bits A_0 and A_1 externally, they can be decoded from the byte enables.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

Table 4a. 80960KA Pin Description: L-Bus Signals (Continued)

Symbol	Type	Name and Function
HOLD/ HLDAR	I	**HOLD:** If the processor is the primary bus master (PBM), the input is interpreted as HOLD, a request from a secondary bus master to acquire the bus. When the processor receives HOLD and grants another master control of the bus, it floats its tri-state bus lines and then asserts HLDA and enters the T_h state. When HOLD is deasserted, the processor will deassert HLDA and go to either the T_i or T_a state. **HOLD ACKNOWLEDGE RECEIVED:** If the processor is a secondary bus master (SBM), the input is HLDAR, which indicates, when HOLDR output is high, that the processor has acquired the bus. Processors and other agents can be told at reset if they are the primary bus master (PBM).
HLDA/ HOLDR	O T.S.	**HOLD ACKNOWLEDGE:** If the processor is a primary bus master, the output is HLDA, which relinquishes control of the bus to another bus master. **HOLD REQUEST:** For secondary bus masters (SBM), the output is HOLDR, which is a request to acquire the bus. The bus is said to be acquired if the agent is a primary bus master and does not have its HLDA output asserted, or if the agent is a secondary bus master and has its HOLD input and HLDA output asserted.
CACHE	O T.S.	**CACHE** indicates if an access is cacheable during a T_a cycle. It is not asserted during any synchronous access, such as a synchronous load or move instruction used for sending an IAC message. The CACHE signal floats to a high impedance state when the processor is idle.

Table 4b. 80960KA Pin Description: Module Support Signals

Symbol	Type	Name and Function
$\overline{\text{BADAC}}$	I	**BAD ACCESS,** if asserted in the cycle following the one in which the last $\overline{\text{READY}}$ of a transaction is asserted, indicates that an unrecoverable error has occurred on the current bus transaction, or that a synchronous load/store instruction has not been acknowledged. **STARTUP:** During system reset, the $\overline{\text{BADAC}}$ signal is interpreted differently. If the signal is high, it indicates that this processor will perform system initialization. If it is low, another processor in the system will perform system initialization instead.
RESET	I	**RESET** clears the internal logic of the processor and causes it to re-initialize. During RESET assertion, the input pins are ignored (except for $\overline{\text{BADAC}}$ and $\overline{\text{IAC}}/\overline{\text{INT}_0}$), the tri-state output pins are placed in a high impedance state, and other output pins are placed in their non-asserted state. RESET must be asserted for at least 41 CLK2 cycles for a predictable RESET. The HIGH to LOW transition of RESET should occur after the rising edge of both CLK2 and the external bus CLK, and before the next rising edge of CLK2.
$\overline{\text{FAILURE}}$	O O.D.	**INITIALIZATION FAILURE** indicates that the processor has failed to initialize correctly. After RESET is deasserted and before the first bus transaction begins, $\overline{\text{FAILURE}}$ is asserted while the processor performs a self-test. If the self-test completes successfully, then $\overline{\text{FAILURE}}$ is deasserted. Next, the processor performs a zero checksum on the first eight words of memory. If it fails, $\overline{\text{FAILURE}}$ is asserted for a second time and remains asserted; if it passes, system initialization continues and $\overline{\text{FAILURE}}$ remains deasserted.
N.C.	N/A	**NOT CONNECTED** indicates pins should not be connected. Never connect any pin marked N.C.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

3

Table 4b. 80960KA Pin Description: Module Support Signals (Continued)

Symbol	Type	Name and Function
$\overline{IAC}$ $\overline{INT0}$	I	**INTERAGENT COMMUNICATION REQUEST/INTERRUPT 0** indicates either that there is a pending IAC message for the processor or an interrupt. The bus interrupt control register determines in which way the signal should be interpreted. To signal an interrupt or IAC request in a synchronous system, this pin (as well as the other interrupt pins) must be enabled by being deasserted for at least one bus cycle and then asserted for at least one additional bus cycle; in an asynchronous system, the pin must remain deasserted for at least two bus cycles and then be asserted for at least two more bus cycles. **LOCAL PROCESSOR NUMBER:** This signal is interpreted differently during system reset. If the signal is at a high voltage level, it indicates that this processor is a primary bus master (Local Processor Number = 0); if it is at a low voltage level, it indicates that this processor is a secondary bus master (Local Processor Number = 1).
INT1	I	**INTERRUPT 1,** like $\overline{INT0}$, provides direct interrupt signaling.
INT2/ INTR	I	**INTERRUPT 2/INTERRUPT REQUEST:** The bus control registers determines how this pin is interpreted. If INT2, it has the same interpretation as the $\overline{INT0}$ and INT1 pins. If INTR, it is used to receive an interrupt request from an external interrupt controller.
$\overline{INT3}$/ $\overline{INTA}$	I/O O.D.	**INTERRUPT 3/INTERRUPT ACKNOWLEDGE:** The bus interrupt control register determines how this pin is interpreted. If $\overline{INT3}$, it has the same interpretation as the $\overline{INT0}$, INT1, and INT2 pins. If $\overline{INTA}$, it is used as an output to control interrupt-acknowledge bus transactions. The $\overline{INTA}$ output is latched on-chip and remains valid during T_d cycles; as an output, it is open-drain.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

ELECTRICAL SPECIFICATIONS

Power and Grounding

The 80960KA is implemented in CHMOS IV technology and has modest power requirements. Its high clock frequency and numerous output buffers (address/data, control, error, and arbitration signals) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 12 V_{CC} and 13 V_{SS} pins separately feed functional units of the 80960KA in the PGA.

Power and ground connections must be made to all power and ground pins of the 80960KA. On the circuit board, all V_{CC} pins must be strapped closely together, preferably on a power plane. Likewise, all V_{SS} pins should be strapped together, preferably on a ground plane. These pins may not be connected together within the chip.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the 80960KA. The processor can cause transient power surges when driving the L-Bus, particularly when it is connected to a large capacitive load.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the processor and decoupling capacitors as much as possible. Capacitors specifically designed for PGA packages are also commercially available and offer the lowest possible inductance.

Connection Recommendations

For reliable operation, always connect unused inputs to an appropriate signal level. In particular, if one or more interrupt lines are not used, they should be pulled up. No inputs should ever be left floating.

All open-drain outputs require a pullup device. While in some cases a simple pullup resistor will be adequate, we recommend a network of pullup and pulldown resistors biased to a valid V_{IH} ($\geq$3.4V) and terminated in the characteristic impedance of the circuit board. Figure 6 shows our recommendations for the resistor values for both a low and high current drive network, which assumes that the circuit board has a characteristic impedance of 100Ω. The advantage of terminating the output signals in this fashion is that it limits signal swing and reduces AC power consumption.

Characteristic Curves

Figure 7 shows the typical supply current requirements over the operating temperature range of the processor at supply voltage (V_{CC}) of 5V. Figure 8 shows the typical power supply current (I_{CC}) required by the 80960KA at various operating frequencies when measured at three input voltage (V_{CC}) levels.

For a given output current (I_{OL}), the curve in Figure 9 shows the worst case output low voltage (V_{OL}).

Figure 10 shows the typical capacitive derating curve for the 80960KA measured from 1.5V on the system clock (CLK) to 1.5V on the falling edge and 1.5V on the rising edge of the L-Bus address/data (LAD) signals.

Test Load Circuit

Figure 13 illustrates the load circuit used to test the 80960KA's tristate pins, and Figure 14 shows the load circuit used to test the open drain outputs. The open drain test uses an active load circuit in the form of a matched diode bridge. Since the open-drain outputs sink current, only the I_{OL} legs of the bridge are necessary and the I_{OH} legs are not used. When the 80960KA driver under test is turned off, the output pin is pulled up to V_{REF} (i.e., V_{OH}). Diode D_1 is turned off and the I_{OL} current source flows through diode D_2.

When the 80960KA open-drain driver under test is on, diode D_1 is also on, and the voltage on the pin being tested drops to V_{OL}. Diode D_2 turns off and I_{OL} flows through diode D_1.

3

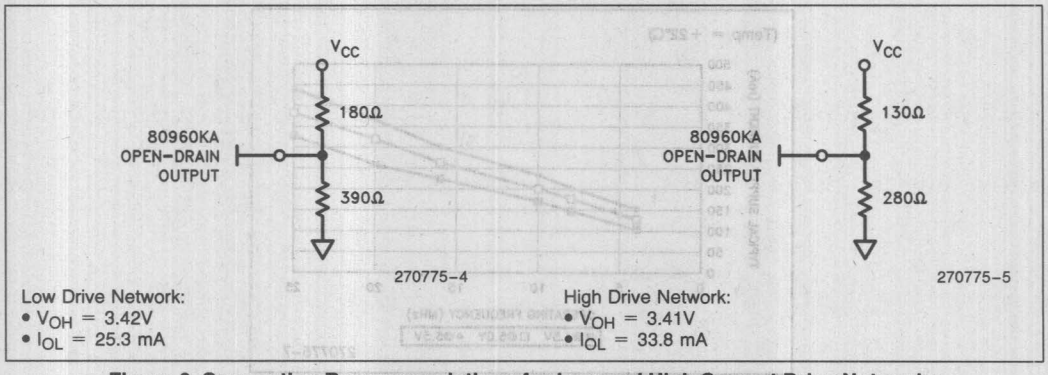


Figure 6. Connection Recommendations for Low and High Current Drive Networks

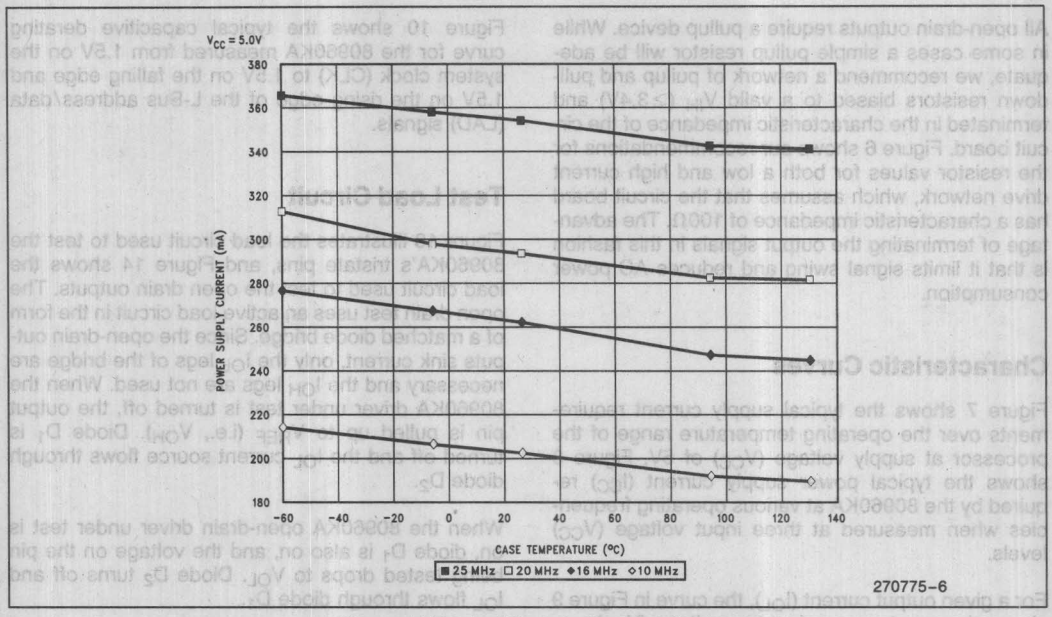


Figure 7. Typical Supply Current (I_{CC})

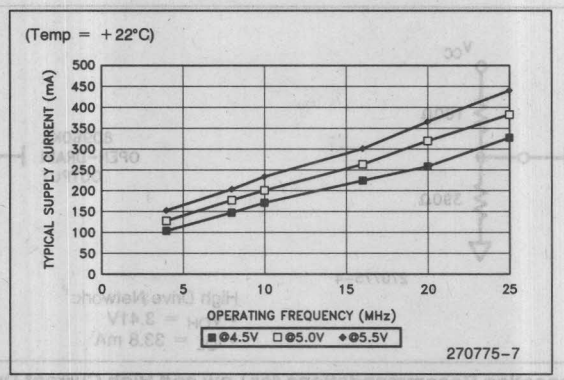


Figure 8. Typical Current vs Frequency

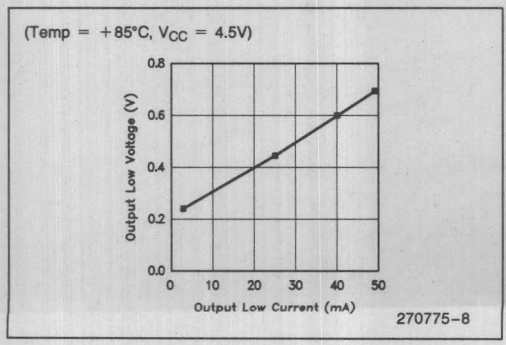


Figure 9. Worst Case Voltage vs Output Current on Open-Drain Pins

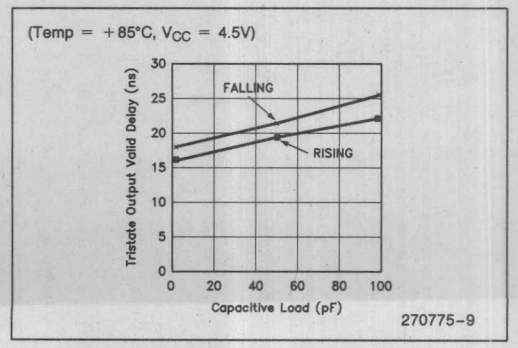


Figure 10. Capacitive Derating Curve

ABSOLUTE MAXIMUM RATINGS*

Operating Temperature . . . . . 0°C to +85°C Case
Storage Temperature . . . . . −65°C to +150°C
Voltage on Any Pin . . . . . −0.5V to V_{CC} + 0.5V
Power Dissipation . . . . . 2.5W (25 MHz)

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

D.C. CHARACTERISTICS

80960KA (10 and 16 MHz): T_{CASE} = 0°C to + 85°C, V_{CC} = 5V ±10%
80960KA (20 and 25 MHz): T_{CASE} = 0°C to + 85°C, V_{CC} = 5V ±5%

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+0.8	V	
V_{CH}	CLK2 Input High Voltage	0.55 V_{CC}	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage		0.45	V	(1, 5)
V_{OH}	Output High Voltage	2.4		V	(2, 4)
I_{CC}	Power Supply Current: 10 MHz 16 MHz 20 MHz 25 MHz		 300 375 420 480	 mA mA mA mA	
I_{LI}	Input Leakage Current		±15	µA	$0 \le V_{IN} \le V_{CC}$
I_{LO}	Output Leakage Current		±15	µA	$0.45 \le V_O \le V_{CC}$
C_{IN}	Input Capacitance		10	pF	f_C = 1 MHz(3)
C_O	I/O or Output Capacitance		12	pF	f_C = 1 MHz(3)
C_{CLK}	Clock Capacitance		10	pF	f_C = 1 MHz(3)

NOTES:
1. For tri-state outputs, this parameter is measured at:
   Address/Data . . . . . 4.0 mA
   Controls . . . . . 5.0 mA
2. This parameter is measured at:
   Address/Data . . . . . −1.0 mA
   Controls . . . . . −0.9 mA
   ALE . . . . . −5.0 mA
3. Input, output, and clock capacitance are not tested.
4. Not measured on open-drain outputs.
5. For open-drain outputs . . . . . 25 mA

A.C. SPECIFICATIONS

This section describes the A.C. specifications for the 80960KA pins. All input and output timings are specified relative to the 1.5V level of the rising edge. Four output timings, the specifications refer to the time it takes the signal to reach 1.5V. For input timings, the specifications refer to the time at which the signal reaches (for input setup) or leaves (for hold time) the TTL levels of LOW (0.8V) or HIGH (2.0V). All AC testing should be done with input clock voltages of 0.4V and 2.4V, except for the clock (CLK2), which should be tested with input voltages of 0.45 V_{CC} and 0.55 V_{CC}.

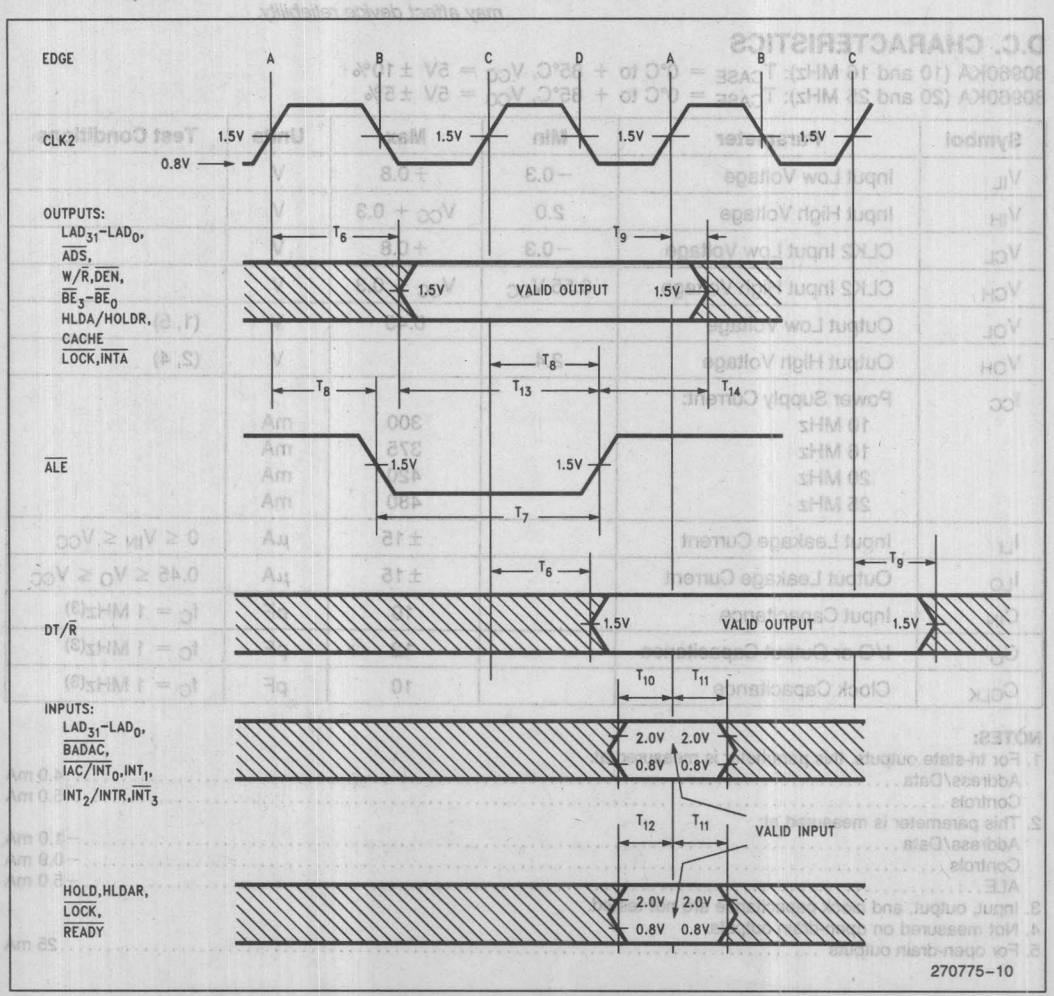


Figure 11. Drive Levels and Timing Relationships for 80960KA Signals

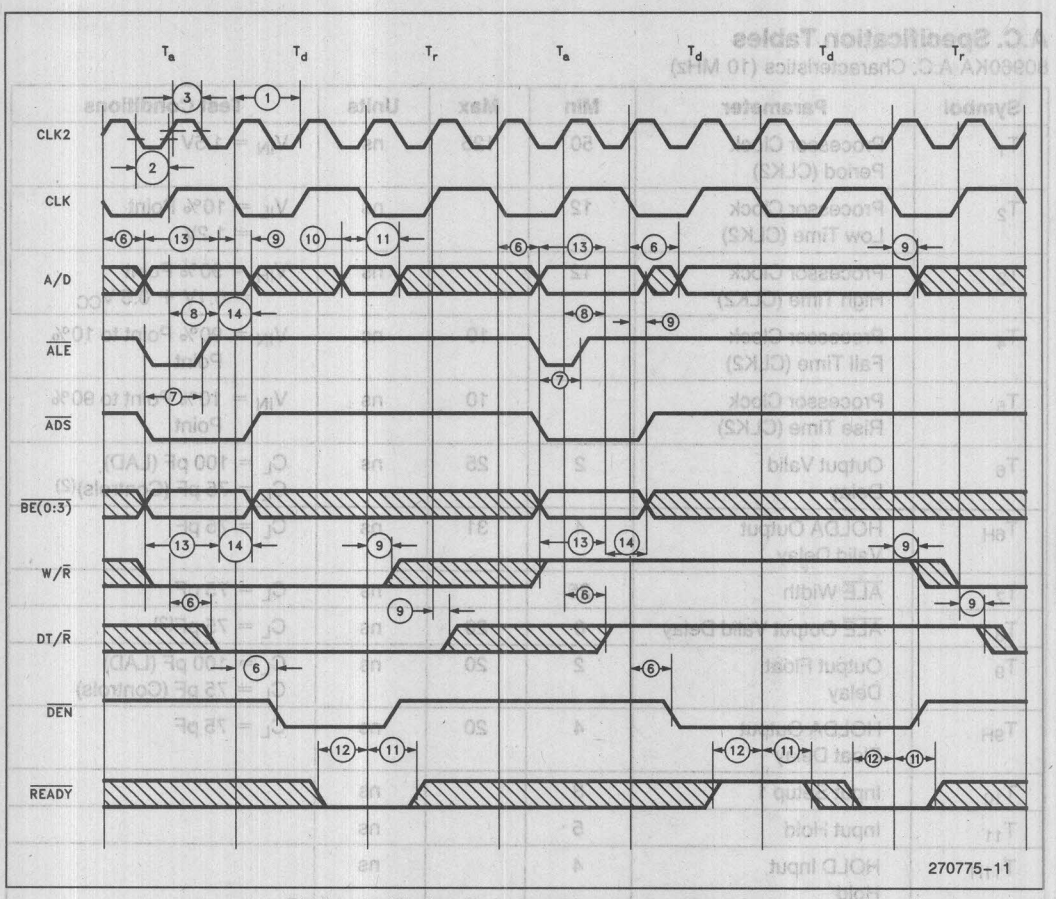


Figure 12. Timing Relationship of L-Bus Signals

A.C. Specification Tables

80960KA A.C. Characteristics (10 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	50	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	12		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	12		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	25	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)(2)
T_{6H}	HOLDA Output Valid Delay	4	31	ns	C_L = 75 pF
T_7	$\overline{ALE}$ Width	25		ns	C_L = 75 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 75 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 75 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	8		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1640		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT_0}$, INT_1, INT_2/INTR, $\overline{INT_3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall time is not tested.

80960KA A.C. Characteristics (16 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	31.25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	8		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	8		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	25	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	31	ns	C_L = 75 pF
T_7	$\overline{ALE}$ Width	15		ns	C_L = 75 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 75 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)(2)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 75 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	8		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1281		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT_0}$, INT_1, INT_2/INTR, $\overline{INT_3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall time is not tested.

80960KA A.C. Characteristics (20 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	6		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	6		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	26	ns	C_L = 50 pF
T_7	$\overline{ALE}$ Width	12		ns	C_L = 50 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 50 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)(2)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1025		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT_0}$, INT_1, INT_2/INTR, $\overline{INT_3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall time is not tested.

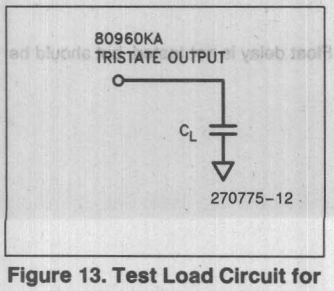


Figure 13. Test Load Circuit for TRI-STATE Output Pins

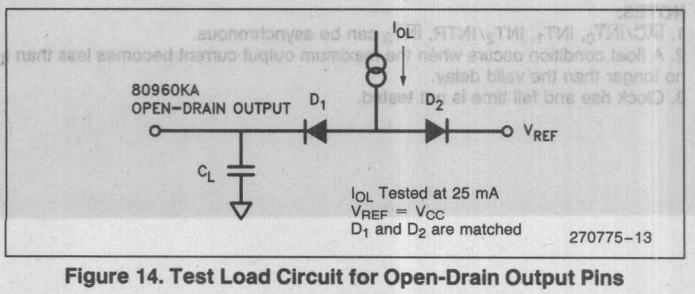


Figure 14. Test Load Circuit for Open-Drain Output Pins

80960KA A.C. Characteristics (25 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	20	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	5		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time	5		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	18	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	24	ns	C_L = 50 pF
T_7	$\overline{ALE}$ Width	12		ns	C_L = 50 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 50 pF(2)
T_9	Output Float Delay	2	18	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	820		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT0}$, INT1, INT2/INTR, $\overline{INT3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall time is not tested.

3

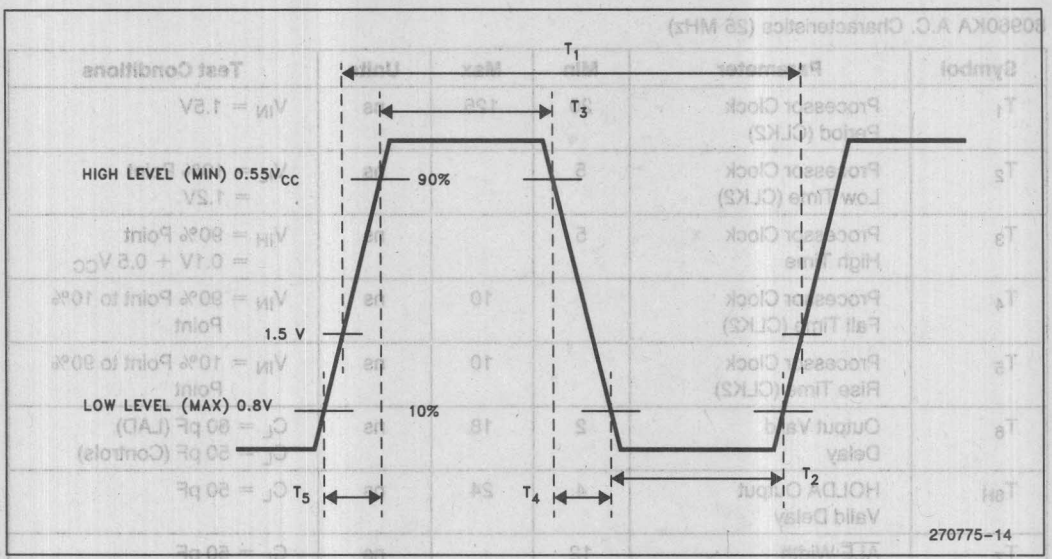


Figure 15. Processor Clock Pulse (CLK2)

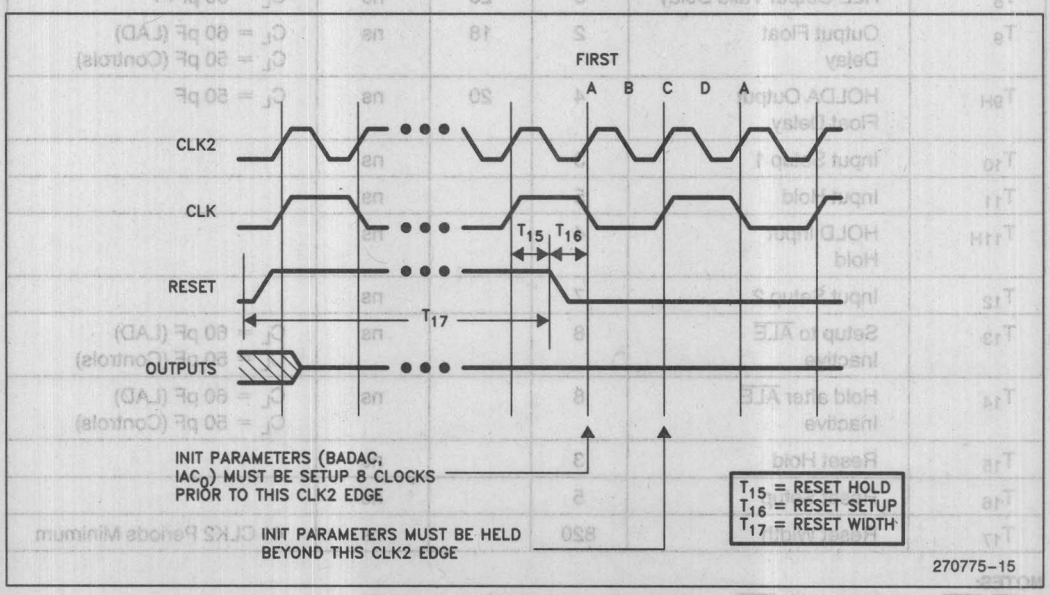


Figure 16. RESET Signal Timing

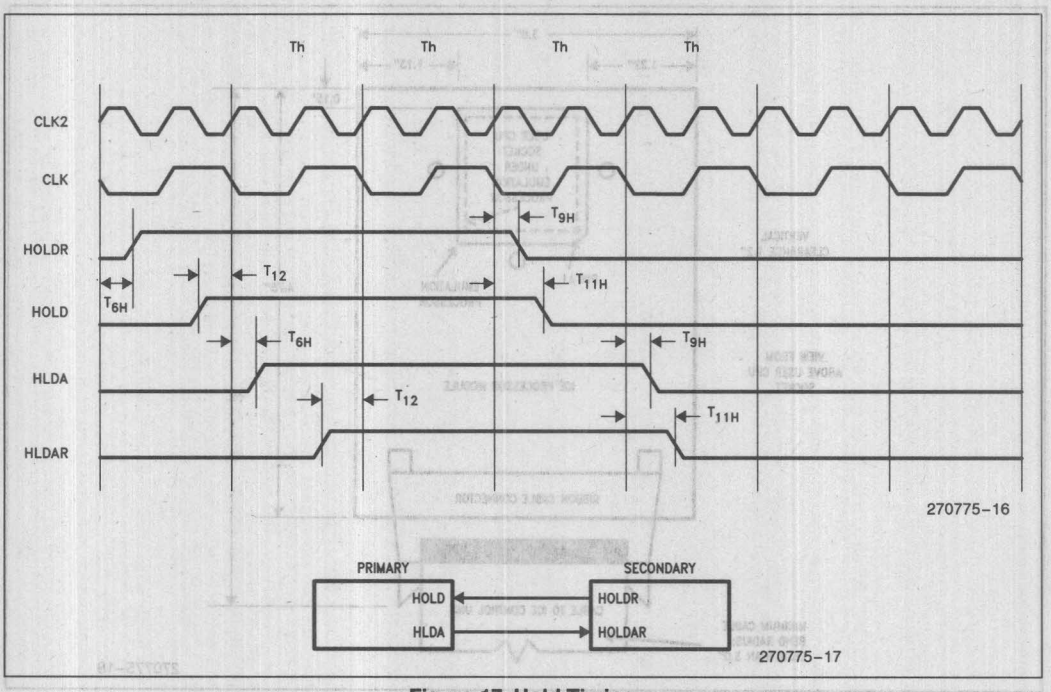


Figure 17. Hold Timing

Design Considerations

Input hold times can be disregarded by the designer whenever the input is removed because a subsequent output from the processor is deasserted (e.g., $\overline{DEN}$ becomes deasserted).

Whenever the processor generates an output that indicates a transition into a subsequent state, any outputs that are specified to be tri-stated in this new state are guaranteed to be tri-stated. For example, in the T_d cycle following a T_a cycle for a read, the minimum output delay of $\overline{DEN}$ is 2 ns, but the maximum float time of LAD is 20 ns. When $\overline{DEN}$ is asserted, however, the LAD outputs are guaranteed to have been tri-stated.

Designing for the ICE-960KB

The 80960KB In-Circuit Emulator assists in debugging both 80960KA and 80960KB hardware and software designs. The product consists of a probe module, cable, and control unit. Because of the high operating frequency of 80960KA systems, the probe module connects directly to the 80960KA socket.

When designing an 80960KA hardware system that uses the ICE-960KB to debug the system, several electrical and mechanical characteristics should be considered. These considerations include capacitive loading, drive requirement, power requirement, and physical layout.

The ICE-960KB probe module increases the load capacitance of each line by up to 25 pF. It also adds one standard Schottky TTL load on the CLK2 line, up to one advanced low-power Schottky TTL load for each control signal line, and one advanced low-power Schottky TTL load for each address/data and byte enable line. These loads originate from the probe module and are driven by the 80960KA processor.

To achieve high noise immunity, the ICE-960KB probe is powered by the user's system. The high-speed probe circuitry draws up to 1.1A plus the maximum current (I_{CC}) of the 80960KA processor.

The mechanical considerations are shown in Figure 18, which illustrates the lateral clearance requirements for the ICE-960KB probe as viewed from above the socket of the 80960KA processor.

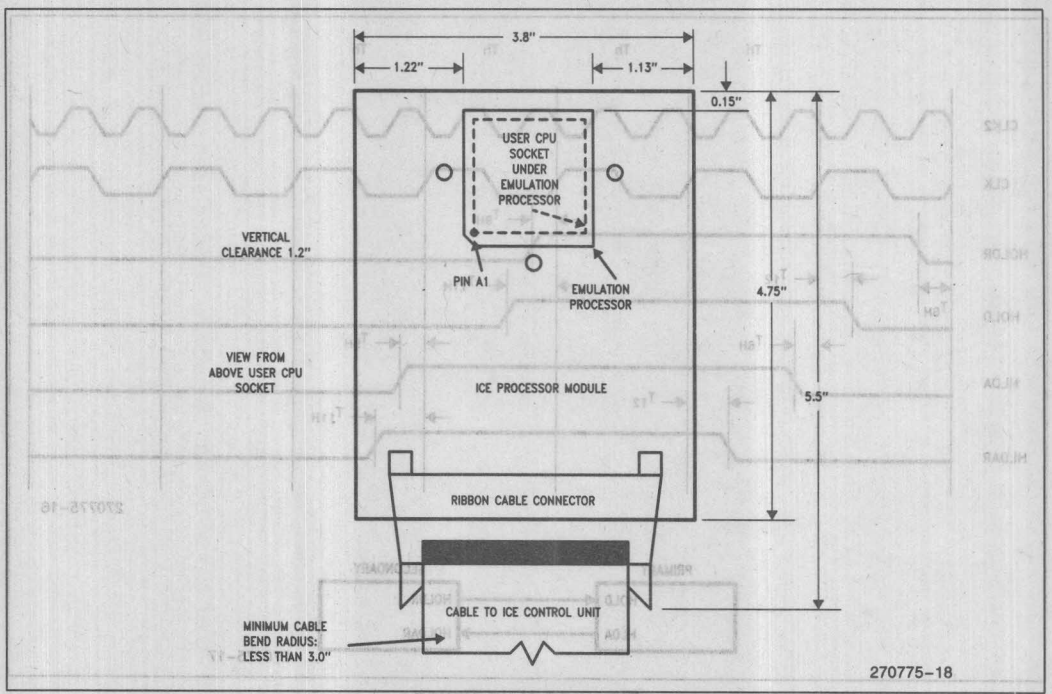


Figure 18. ICE-960KB Lateral Clearance Requirements

MECHANICAL DATA

Package Dimensions and Mounting

The 80960KA is available in two different packages: a 132-lead ceramic pin-grid array (PGA) and a 132-lead plastic quad flat pack (PQFP). Pins in the ceramic package are arranged 0.100 inch (2.54 mm) center-to-center, in a 14 by 14 matrix, three rows around. (See Figure 19.) The plastic package uses fine-pitch gull wing leads arranged in a single row along the perimeter of the package with 0.025 inch (0.64 mm) spacing. (See Figure 20.) Dimensions are given in Figure 21 and Table 7.

There are a wide variety of sockets available for the ceramic PGA package including low-insertion or zero-insertion force mountings, and a choice of terminals such as soldertail, surface mount, or wire wrap. Several applicable sockets are shown in Figure 22.

The PQFP is normally surface mounted to take best advantage of the plastic package's small footprint and low cost. In some applications, however, designers may prefer to use a socket, either to improve heat dissipation or reduce repair costs. Figures 23a and 23b show two of the many sockets available.

Pin Assignment

The PGA and PQFP have different pin assignments. Figure 24 shows the view from the bottom of the PGA (pins facing up) and Figure 25 shows a view from the top of the PGA (pins facing down). Figures 20 and 32 show the top view of the PQFP; notice that the pins are numbered in order from 1 to 132 around the package's perimeter. Tables 5 and 6 list the function of each pin in the PGA, and Tables 8 and 9 list the function of each pin in the PQFP.

V_{CC} and GND connections must be made to multiple V_{CC} and GND pins. Each V_{CC} and GND pin must be connected to the appropriate voltage or ground and externally strapped close to the package. We recommend that you include separate power and ground planes in your circuit board for power distribution.

NOTE:
Pins identified as N.C., "No Connect," should never be connected. The 80960KA PGA and PQFP packages both contain 53 N.C. pins

Package Thermal Specification

The 80960KA is specified for operation when case temperature is within the range 0°C to +85°C. The case temperature should be measured at the top center of the package as shown in Figure 26.

The ambient temperature can be calculated from θ_{jc} and θ_{ja} by using the following equations:

$$T_J = T_C + P^*\theta_{jc}$$
$$T_A = T_J - P^*\theta_{ja}$$
$$T_C = T_A + P^*[\theta_{ja} - \theta_{jc}]$$

Values for θ_{ja} and θ_{jc} are given in Table 10 for the PGA package and in Table 11 for the PQFP for various airflows. Note that the θ_{ja} for the PGA package can be reduced by adding a heatsink, while a heatsink is not generally used with the plastic package since it is intended to be surface mounted. The maximum allowable ambient temperature (T_A) permitted without exceeding T_C is shown by the charts in Figures 27 through 30 for 10 MHz, 16 MHz, 20 MHz, and 25 MHz respectively.

The curves assume the maximum permitted supply current (I_{CC}) at each speed, V_{CC} of 5.0V, and a T_{CASE} of +85°C.

If you will be using the 80960KA in a harsh environment where the ambient temperature may exceed the limits for the normal commercial part, you should consider using an extended temperature part. These parts are designed by the prefix "TA" and are available at 10 MHz, 16 MHz and 20 MHz in the ceramic PGA package. Figure 30 shows the maximum allowable ambient temperature for the 20 MHz extended temperature TA80960KA at various airflows. The curve assumes an I_{CC} of 420 mA, V_{CC} of 5.0V, and a T_{CASE} of +125°C.

WAVEFORMS

Figures 32 through 37 show the waveforms for various transactions on the 80960KA's local bus.

SUPPORT COMPONENTS

85C960 Burst Bus Controller

The Intel 85C960 performs burst logic, ready generation, and address decode for the 80960KA and 80960KB. The burst logic supports both standard and burst mode memories and peripherals. The ready generation and timing control supports 0 to 15 wait states across eight address ranges for read/write and burst accesses. The address decoder decodes eight address inputs into four external and four internal chip selects. The wait state and chip select values may be programmed by the user; the timing control and burst logic are fixed.

The 85C960 operates with the 80960KA and 80960KB at all frequencies and consumes only 50 mA at 25 MHz. The 85C960 is housed in a 28-pin, 300-mil ceramic DIP and plastic DIP packages or 28-pin PLCC package for surface mount. In the ceramic DIP package the part is UV-erasable, which makes it easy to revise designs. Order the 85C960 data sheet (No. 290192) for full details.

3

27960KX Burst Mode EPROM

Intel 27960KX one-megabit EPROM is designed specifically to support the 80960KA and 80960KB. It uses a burst interface to offer near zero wait-state performance without the high cost of alternative memory technologies. The 27960KX removes the need for "dumping" code and data stored in slow EPROMs or ROMs into expensive high-speed "shadow" RAM.

Internally, the 27960KX is organized in blocks of four bytes that are accessed sequentially. The address of the four-byte block is latched and incremented internally. After a set number of wait-states (1 or 2), data is output one word at a time each subsequent clock cycle. High-performance outputs provide zero wait-state data-to-data burst accesses. Extra power and ground pins dedicated to the output reduce the effect of fast output switching on the device. The 27960KX offers 1-0-0-0 performance at 20 MHz and 2-0-0-0 performance at 25 MHz. Full details can be found in the 27960KX data sheet (No. 290237)

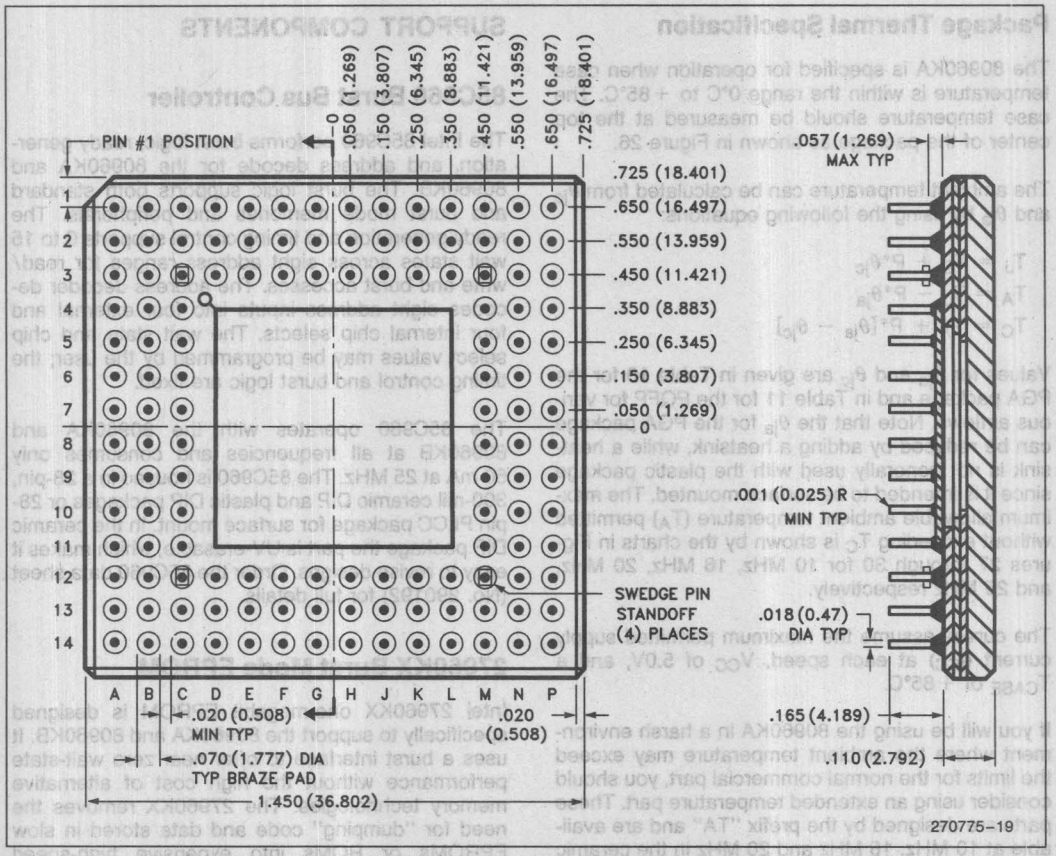


Figure 19. A 132-Lead Pin-Grid Array (PGA) Used to Package the 80960KA

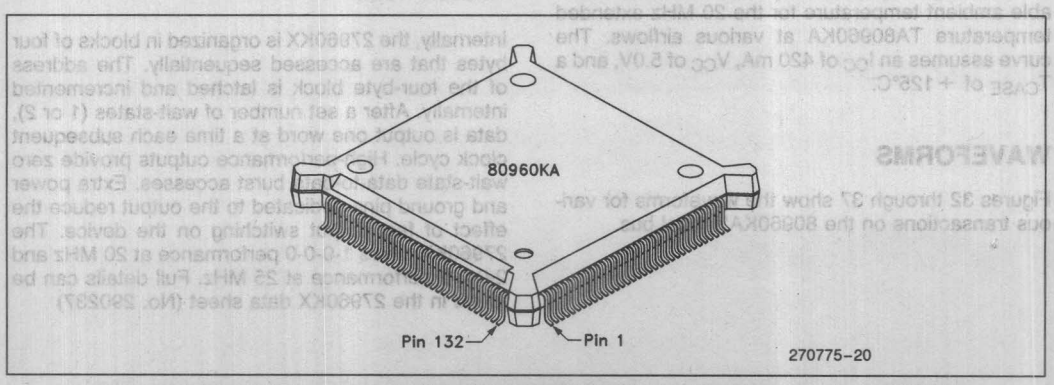


Figure 20. The 132-Lead Plastic Quad Flat Pack (PQFP) used to Package the 80960KA

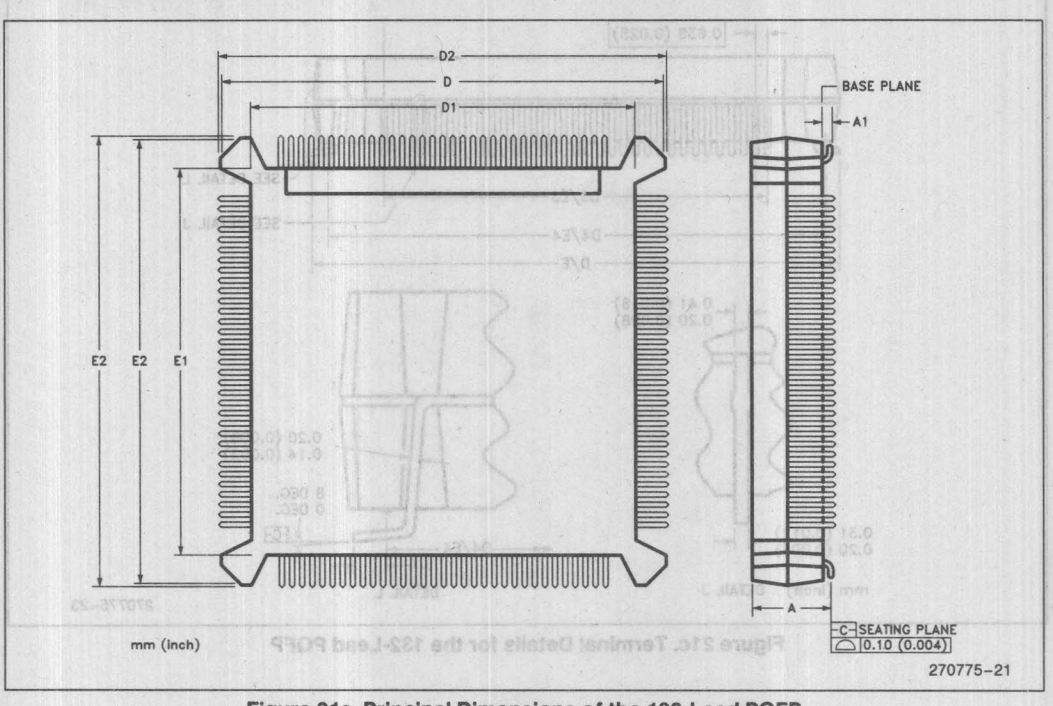


Figure 21a. Principal Dimensions of the 132-Lead PQFP

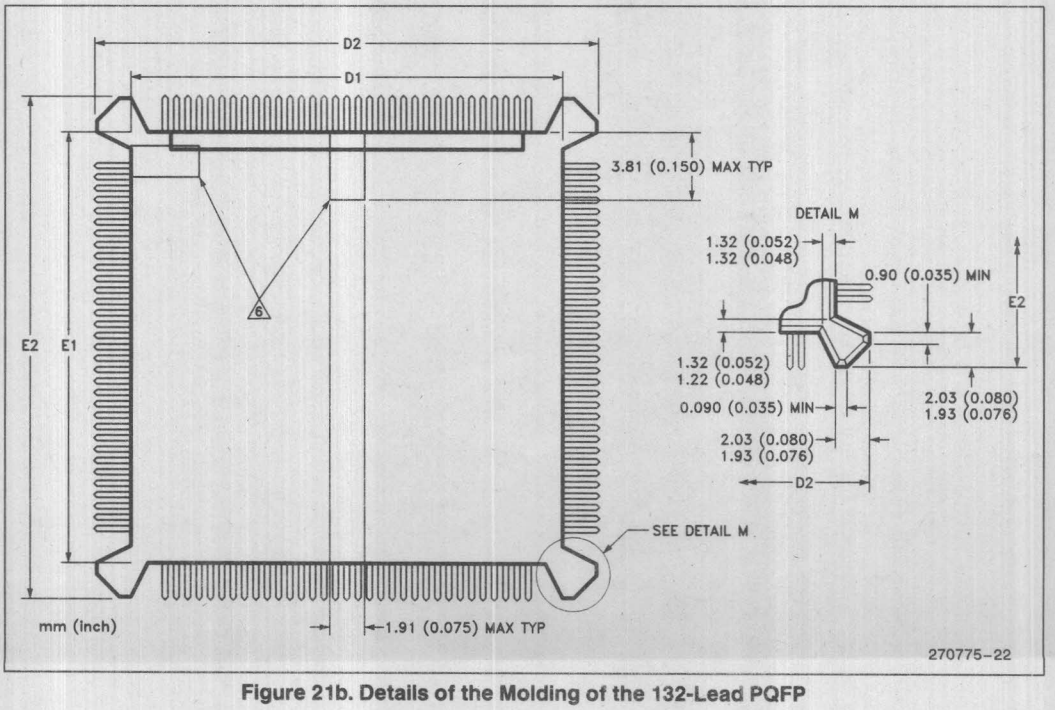


Figure 21b. Details of the Molding of the 132-Lead PQFP

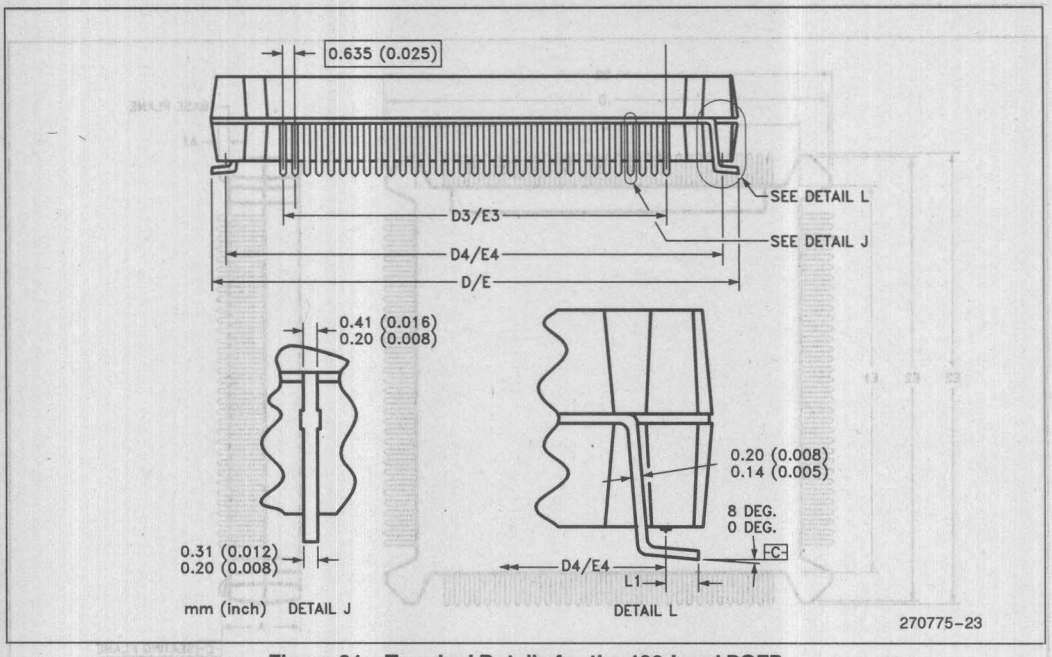


Figure 21c. Terminal Details for the 132-Lead PQFP

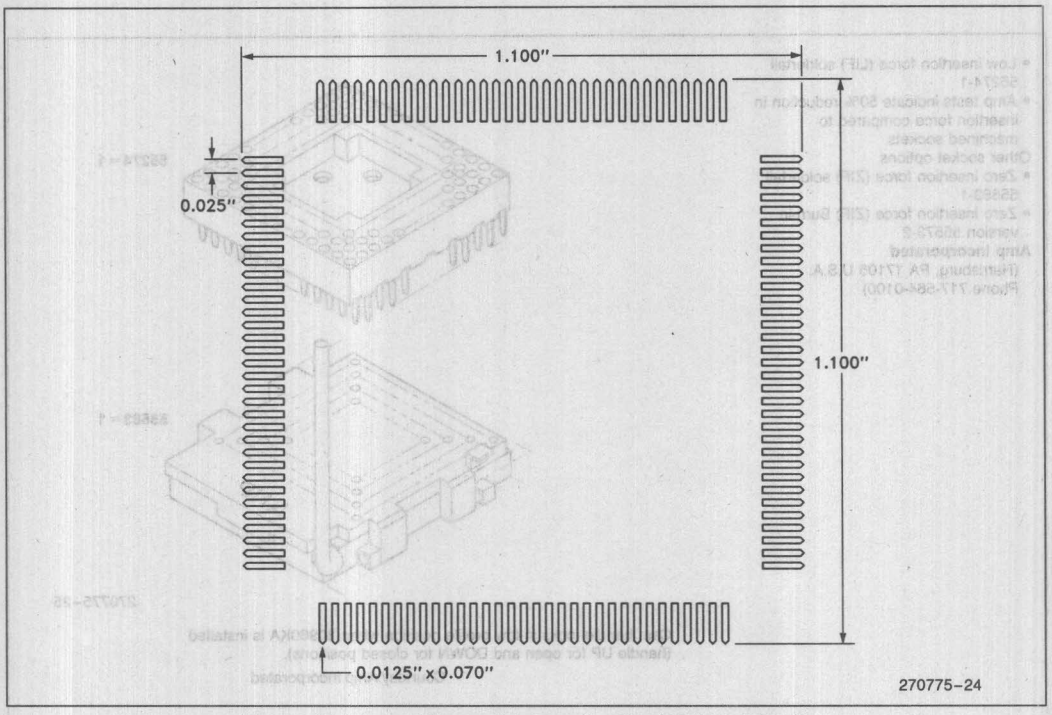


Figure 21d. Board Footprint Area for the 132-Lead PQFP

Table 7. Package Dimension: 80960KA PQFP

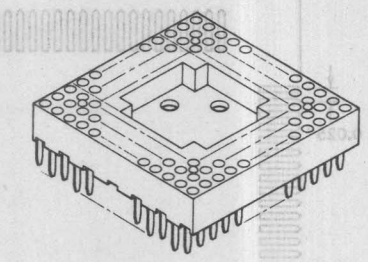
Symbol	Description	Inches		MM	
		Min	Max	Min	Max
N	Leadcount	132 Leads		132 Leads	
A	Package Height	0.160	0.170	4.060	4.320
A1	Standoff	0.020	0.030	0.510	0.760
D,E	Terminal Dimension	1.075	1.085	27.310	27.560
D1,E1	Package Body	0.947	0.953	24.050	24.210
D2,E2	Bumper Distance Without Flash With Flash	 1.097 1.097	 1.103 1.110	 27.860 27.860	 28.010 28.190
D3,E3	Lead Dimension	0.800 REF		20.32 REF	
D4,E4	Foot Radius Location	1.023	1.037	25.890	26.330
L1	Foot Length	0.020	0.030	0.510	0.760

- Low insertion force (LIF) soldertail 55274-1
- Amp tests indicate 50% reduction in insertion force compared to machined sockets

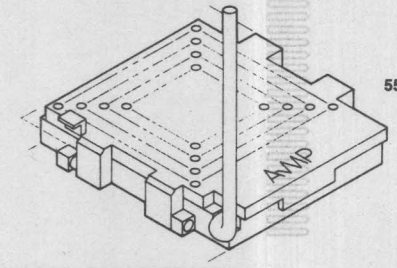
Other socket options

- Zero insertion force (ZIF) soldertail 55583-1
- Zero insertion force (ZIF) Burn-in version 55573-2

Amp Incorporated
(Harrisburg, PA 17105 U.S.A.
Phone 717-564-0100)



55274 = 1



55583 = 1

270775-25

Cam handle locks in low profile position when 80960KA is installed (handle UP for open and DOWN for closed positions).

Courtesy Amp Incorporated

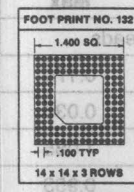
Peel-A-Way* Mylar and Kapton Socket Terminal Carriers

- Low insertion force surface mount CS132-37TG
- Low insertion force soldertail CS132-01TG
- Low insertion force wire-wrap CS132-02TG (two-level) CS132-03TG (thee-level)
- Low insertion force press-fit CS132-05TG

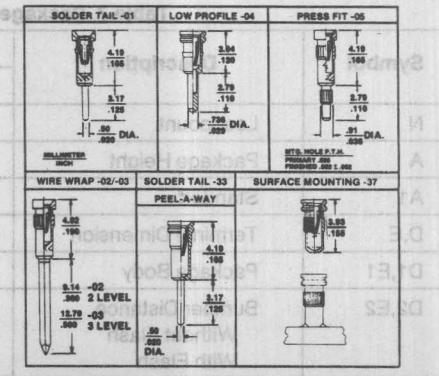
Advanced Interconnections
(5 Division Street)
Warwick, RI 02818 U.S.A.
Phone 401-885-0485)

Peel-A-Way Carrier No. 132:
Kapton Carrier is KS132
Mylar Carrier is MS132

Molded Plastic Body KS132 is shown below:



270775-26



270775-27

Courtesy Advanced Interconnections
(Peel-A-Way Terminal Carriers
U.S. Patent No. 4442938)

*Peel-A-Way is a trademark of Advanced Interconnections.

Figure 22. Several Socket Options for Mounting the 80960KA

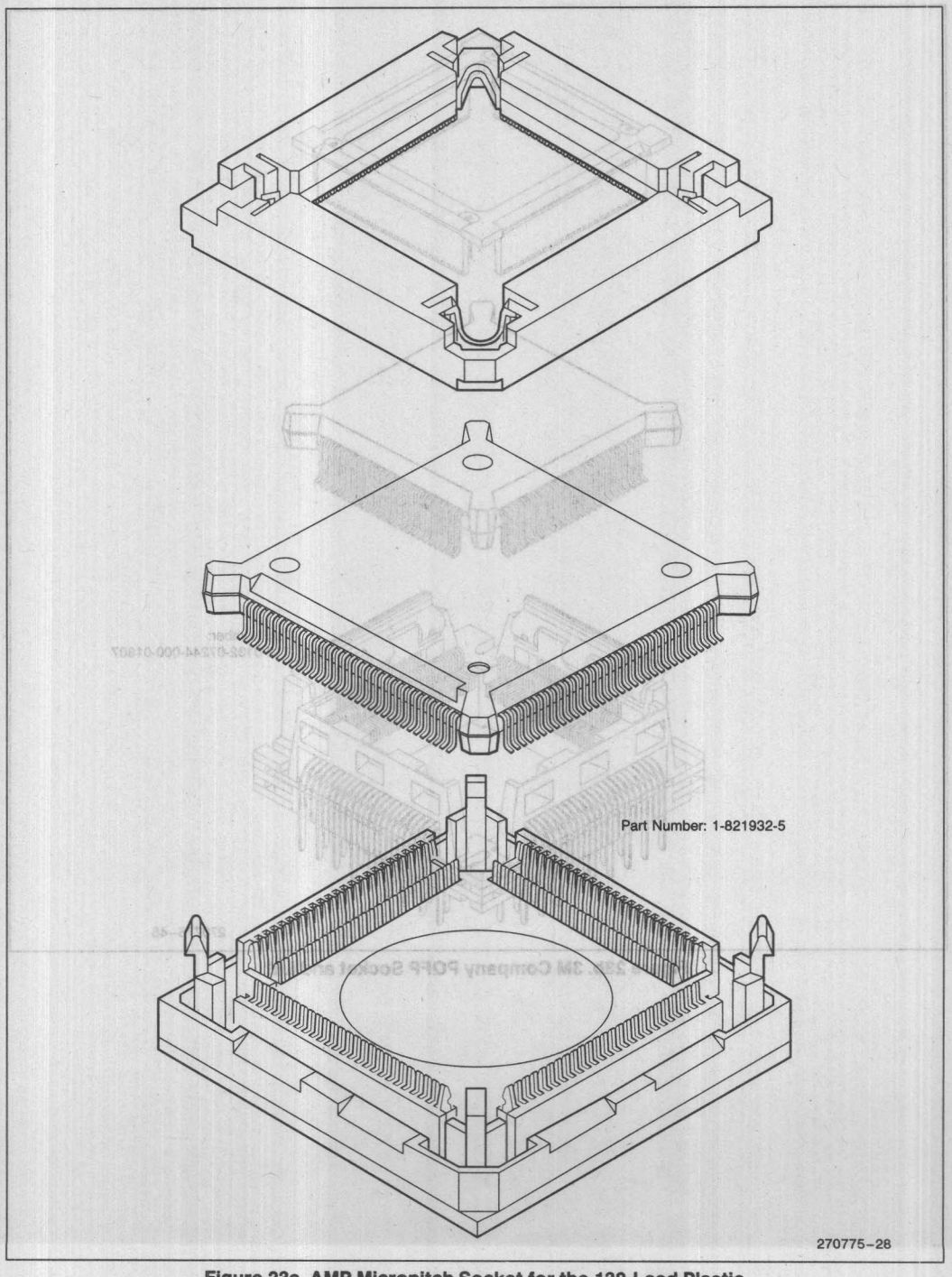
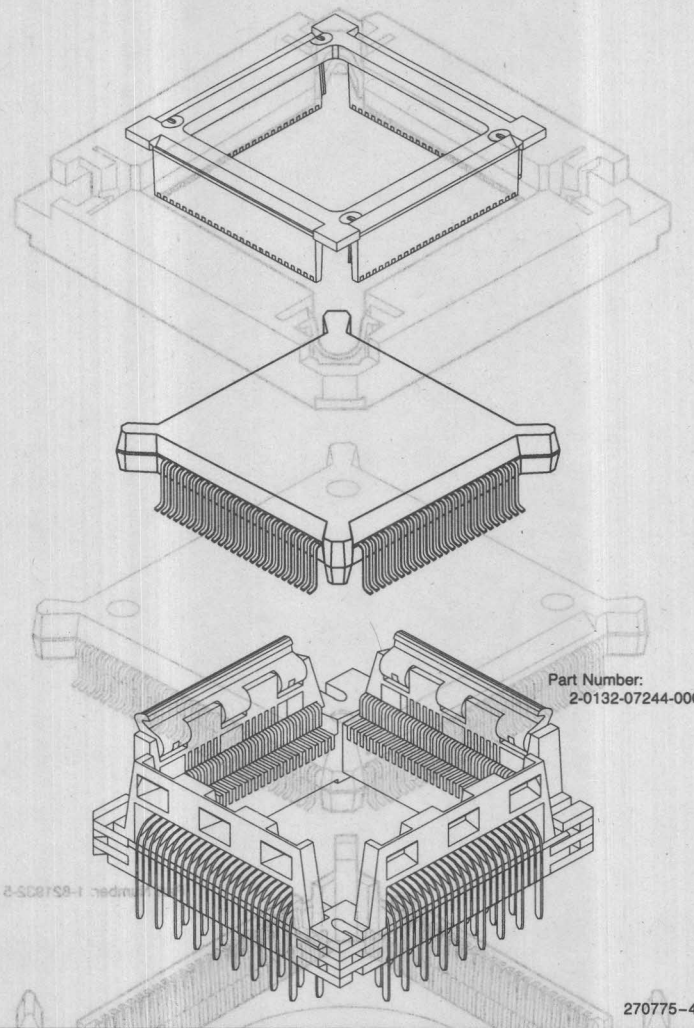


Figure 23a. AMP Micropitch Socket for the 132-Lead Plastic Quad Flat Pack, 0.025" Lead Spacing, Gull Wing Leads



Part Number:
2-0132-07244-000-01807

270775-45

Figure 23b. 3M Company PQFP Socket and Lid

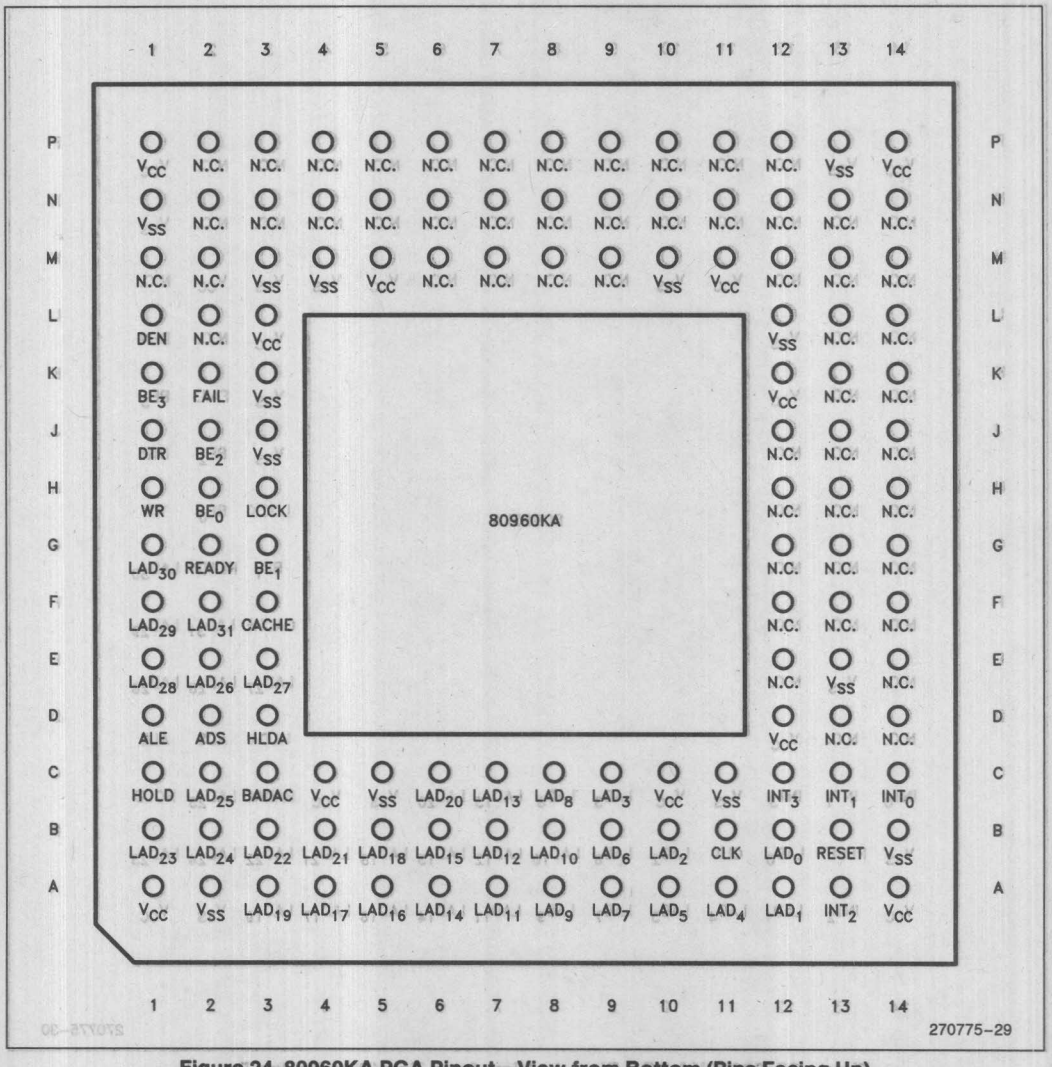


Figure 24. 80960KA PGA Pinout—View from Bottom (Pins Facing Up)

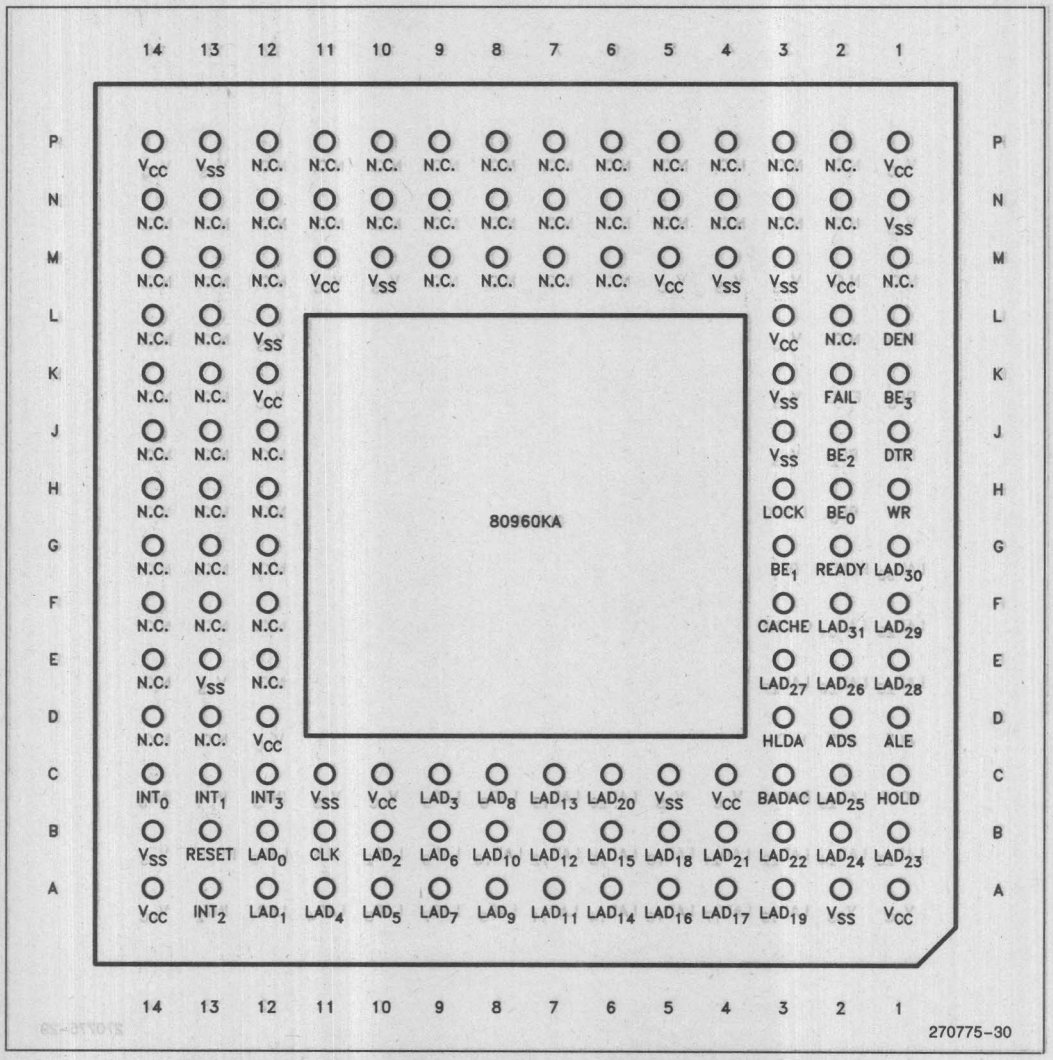


Figure 25. 80960KA PGA Pinout—View from Top (Pins Facing Down)

Table 5. 80960KA PGA Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
A1	V_{CC}	C6	LAD_{20}	H1	$W/\overline{R}$	M10	V_{SS}
A2	V_{SS}	C7	LAD_{13}	H2	$\overline{BE_0}$	M11	V_{CC}
A3	LAD_{19}	C8	LAD_8	H3	$\overline{LOCK}$	M12	N.C.
A4	LAD_{17}	C9	LAD_3	H12	N.C.	M13	N.C.
A5	LAD_{16}	C10	V_{CC}	H13	N.C.	M14	N.C.
A6	LAD_{14}	C11	V_{SS}	H14	N.C.	N1	V_{SS}
A7	LAD_{11}	C12	$\overline{INT_3}/\overline{INTA}$	J1	$DT/\overline{R}$	N2	N.C.
A8	LAD_9	C13	INT_1	J2	$\overline{BE_2}$	N3	N.C.
A9	LAD_7	C14	$\overline{IAC}/\overline{INT_0}$	J3	V_{SS}	N4	N.C.
A10	LAD_5	D1	$\overline{ALE}$	J12	N.C.	N5	N.C.
A11	LAD_4	D2	$\overline{ADS}$	J13	N.C.	N6	N.C.
A12	LAD_1	D3	HLDA/HLDR	J14	N.C.	N7	N.C.
A13	INT_2/INTR	D12	V_{CC}	K1	$\overline{BE_3}$	N8	N.C.
A14	V_{CC}	D13	N.C.	K2	$\overline{FAILURE}$	N9	N.C.
B1	LAD_{23}	D14	N.C.	K3	V_{SS}	N10	N.C.
B2	LAD_{24}	E1	LAD_{28}	K12	V_{CC}	N11	N.C.
B3	LAD_{22}	E2	LAD_{26}	K13	N.C.	N12	N.C.
B4	LAD_{21}	E3	LAD_{27}	K14	N.C.	N13	N.C.
B5	LAD_{18}	E12	N.C.	L1	$\overline{DEN}$	N14	N.C.
B6	LAD_{15}	E13	V_{SS}	L2	N.C.	P1	V_{CC}
B7	LAD_{12}	E14	N.C.	L3	V_{CC}	P2	N.C.
B8	LAD_{10}	F1	LAD_{29}	L12	V_{SS}	P3	N.C.
B9	LAD_6	F2	LAD_{31}	L13	N.C.	P4	N.C.
B10	LAD_2	F3	CACHE	L14	N.C.	P5	N.C.
B11	CLK2	F12	N.C.	M1	N.C.	P6	N.C.
B12	LAD_0	F13	N.C.	M2	V_{CC}	P7	N.C.
B13	RESET	F14	N.C.	M3	V_{SS}	P8	N.C.
B14	V_{SS}	G1	LAD_{30}	M4	V_{SS}	P9	N.C.
C1	HOLD/HLDAR	G2	$\overline{READY}$	M5	V_{CC}	P10	N.C.
C2	LAD_{25}	G3	$\overline{BE_1}$	M6	N.C.	P11	N.C.
C3	$\overline{BADAC}$	G12	N.C.	M7	N.C.	P12	N.C.
C4	V_{CC}	G13	N.C.	M8	N.C.	P13	V_{SS}
C5	V_{SS}	G14	N.C.	M9	N.C.	P14	V_{CC}

Table 6. 80960KA PGA Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	D2	LAD_{15}	B6	N.C.	J14	N.C.	P9
$\overline{ALE}$	D1	LAD_{16}	A5	N.C.	K13	N.C.	P10
$\overline{BADAC}$	C3	LAD_{17}	A4	N.C.	K14	N.C.	P11
$\overline{BE_0}$	H2	LAD_{18}	B5	N.C.	L13	N.C.	P12
$\overline{BE_1}$	G3	LAD_{19}	A3	N.C.	L14	N.C.	L2
$\overline{BE_2}$	J2	LAD_{20}	C6	N.C.	M1	$\overline{READY}$	G2
$\overline{BE_3}$	K1	LAD_{21}	B4	N.C.	M6	RESET	B13
CACHE	F3	LAD_{22}	B3	N.C.	M7	V_{CC}	A1
CLK2	B11	LAD_{23}	B1	N.C.	M8	V_{CC}	A14
$\overline{DEN}$	L1	LAD_{24}	B2	N.C.	M9	V_{CC}	C4
DT/$\overline{R}$	J1	LAD_{25}	C2	N.C.	M12	V_{CC}	C10
$\overline{FAILURE}$	K2	LAD_{26}	E2	N.C.	M13	V_{CC}	D12
HLDA/HOLDR	D3	LAD_{27}	E3	N.C.	M14	V_{CC}	K12
HOLD/HLDAR	C1	LAD_{28}	E1	N.C.	N2	V_{CC}	L3
$\overline{IAC}/\overline{INT_0}$	C14	LAD_{29}	F1	N.C.	N3	V_{CC}	M2
INT_1	C13	LAD_{30}	G1	N.C.	N4	V_{CC}	M5
INT_2/INTR	A13	LAD_{31}	F2	N.C.	N5	V_{CC}	M11
$\overline{INT_3}/\overline{INTA}$	C12	$\overline{LOCK}$	H3	N.C.	N6	V_{CC}	P1
LAD_0	B12	N.C.	D13	N.C.	N7	V_{CC}	P14
LAD_1	A12	N.C.	D14	N.C.	N8	V_{SS}	A2
LAD_2	B10	N.C.	E12	N.C.	N9	V_{SS}	B14
LAD_3	C9	N.C.	E14	N.C.	N10	V_{SS}	C5
LAD_4	A11	N.C.	F12	N.C.	N11	V_{SS}	C11
LAD_5	A10	N.C.	F13	N.C.	N12	V_{SS}	E13
LAD_6	B9	N.C.	F14	N.C.	N13	V_{SS}	J3
LAD_7	A9	N.C.	G12	N.C.	N14	V_{SS}	K3
LAD_8	C8	N.C.	G13	N.C.	P2	V_{SS}	L12
LAD_9	A8	N.C.	G14	N.C.	P3	V_{SS}	M3
LAD_{10}	B8	N.C.	H12	N.C.	P4	V_{SS}	M4
LAD_{11}	A7	N.C.	H13	N.C.	P5	V_{SS}	M10
LAD_{12}	B7	N.C.	H14	N.C.	P6	V_{SS}	N1
LAD_{13}	C7	N.C.	J12	N.C.	P7	V_{SS}	P13
LAD_{14}	A6	N.C.	J13	N.C.	P8	W/$\overline{R}$	H1

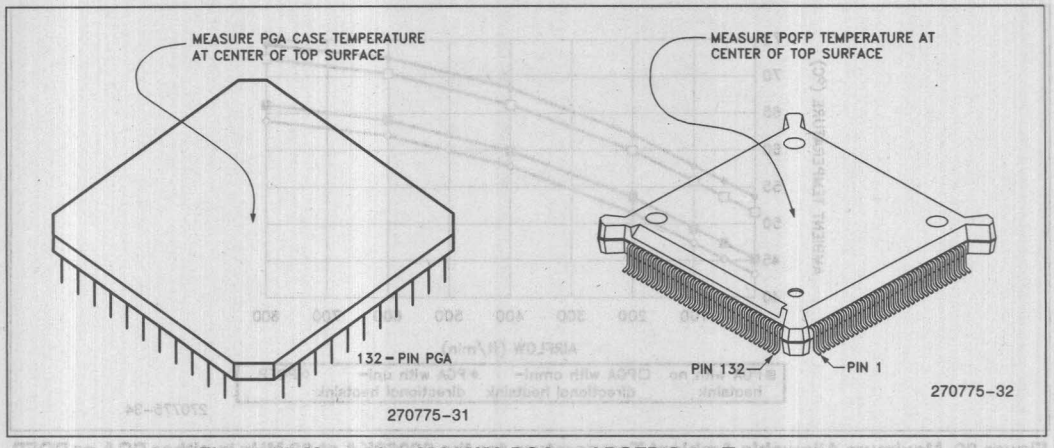


Figure 26. Measuring 80960KA PGA and PQFP Case Temperature

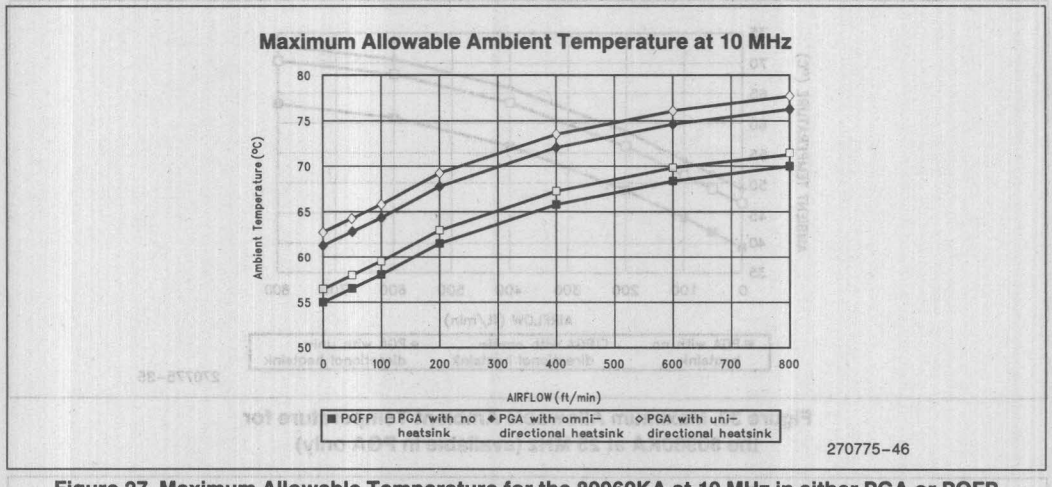


Figure 27. Maximum Allowable Temperature for the 80960KA at 10 MHz in either PGA or PQFP

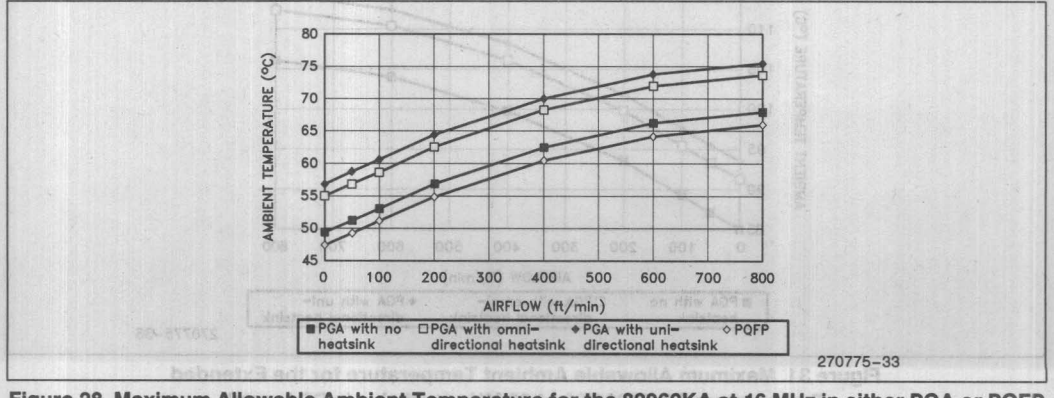


Figure 28. Maximum Allowable Ambient Temperature for the 80960KA at 16 MHz in either PGA or PQFP

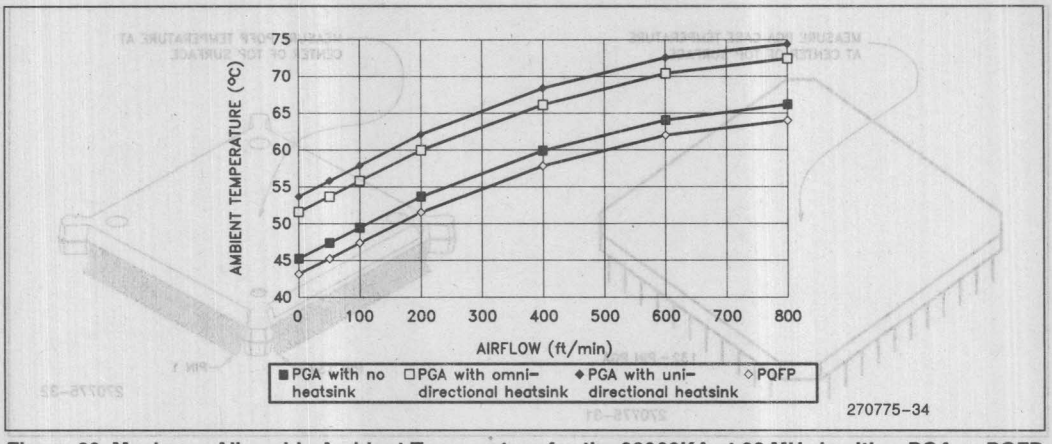


Figure 29. Maximum Allowable Ambient Temperature for the 80960KA at 20 MHz in either PGA or PQFP

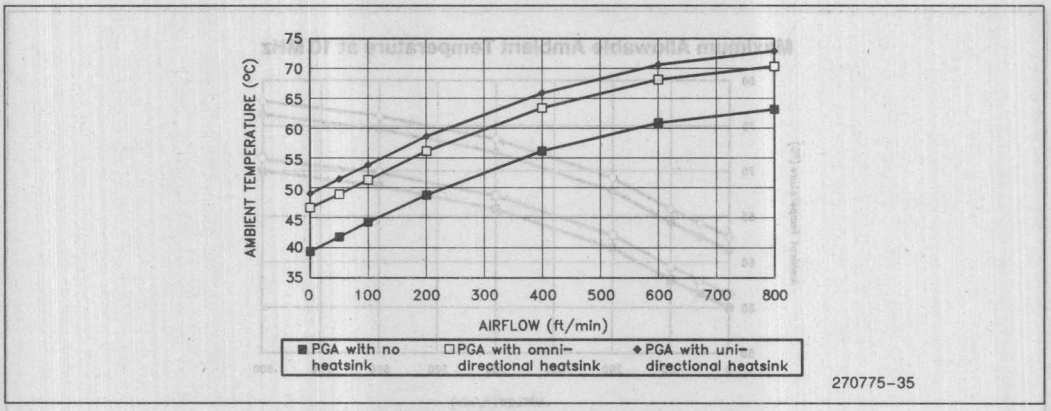


Figure 30. Maximum Allowable Ambient Temperature for the 80960KA at 25 MHz (available in PGA only)

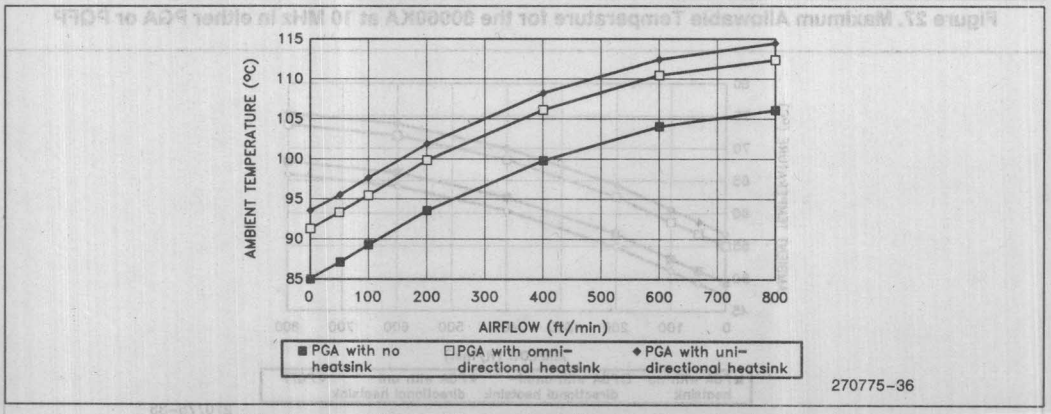


Figure 31. Maximum Allowable Ambient Temperature for the Extended Temperature TA-80960KA at 20 MHz (available in PGA only)

Figure 32. 80960KA PQFP Pinout—View from Top

Table 8. 80960KA Plastic Package Pinout—In Pin Order

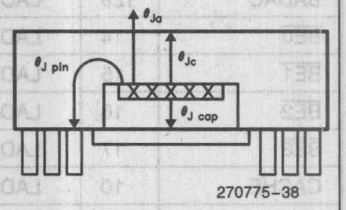
Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
1	HLDA/HOLDR	34	N.C.	67	V_{SS}	100	LAD0
2	$\overline{ALE}$	35	V_{CC}	68	V_{SS}	101	LAD1
3	LAD26	36	V_{CC}	69	N.C.	102	LAD2
4	LAD27	37	N.C.	70	V_{CC}	103	V_{SS}
5	LAD28	38	N.C.	71	V_{CC}	104	LAD3
6	LAD29	39	N.C.	72	N.C.	105	LAD4
7	LAD30	40	N.C.	73	N.C.	106	LAD5
8	LAD31	41	N.C.	74	N.C.	107	LAD6
9	V_{SS}	42	N.C.	75	N.C.	108	LAD7
10	CACHE	43	N.C.	76	N.C.	109	LAD8
11	W/$\overline{R}$	44	N.C.	77	N.C.	110	LAD9
12	$\overline{READY}$	45	N.C.	78	N.C.	111	LAD10
13	DT/$\overline{R}$	46	N.C.	79	V_{SS}	112	LAD11
14	$\overline{BE0}$	47	N.C.	80	V_{SS}	113	LAD12
15	$\overline{BE1}$	48	N.C.	81	N.C.	114	V_{SS}
16	$\overline{BE2}$	49	N.C.	82	V_{CC}	115	LAD13
17	$\overline{BE3}$	50	N.C.	83	V_{CC}	116	LAD14
18	$\overline{FAILURE}$	51	N.C.	84	N.C.	117	LAD15
19	V_{SS}	52	V_{SS}	85	$\overline{IAC}$/$\overline{INT0}$	118	LAD16
20	$\overline{LOCK}$	53	V_{SS}	86	INT1	119	LAD17
21	$\overline{DEN}$	54	N.C.	87	INT2/INTR	120	LAD18
22	DEBUG	55	V_{CC}	88	$\overline{INT3}$/$\overline{INTA}$	121	LAD19
23	N.C.	56	V_{CC}	89	N.C.	122	LAD20
24	N.C.	57	N.C.	90	V_{SS}	123	LAD21
25	N.C.	58	N.C.	91	CLK2	124	LAD22
26	V_{SS}	59	N.C.	92	V_{CC}	125	V_{SS}
27	V_{SS}	60	N.C.	93	RESET	126	LAD23
28	N.C.	61	N.C.	94	N.C.	127	LAD24
29	V_{CC}	62	N.C.	95	N.C.	128	LAD25
30	V_{CC}	63	N.C.	96	N.C.	129	$\overline{BADAC}$
31	N.C.	64	N.C.	97	N.C.	130	HOLD/HLDAR
32	V_{SS}	65	N.C.	98	N.C.	131	N.C.
33	V_{SS}	66	N.C.	99	N.C.	132	$\overline{ADS}$

Table 9. 80960KA Plastic Package Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	132	LAD22	124	N.C.	46	N.C.	99
$\overline{ALE}$	2	LAD23	126	N.C.	47	N.C.	131
$\overline{BADAC}$	129	LAD24	127	N.C.	48	$\overline{READY}$	12
$\overline{BE0}$	14	LAD25	128	N.C.	49	RESET	93
$\overline{BE1}$	15	LAD26	3	N.C.	50	V_{CC}	29
$\overline{BE2}$	16	LAD27	4	N.C.	51	V_{CC}	30
$\overline{BE3}$	17	LAD28	5	N.C.	54	V_{CC}	35
CACHE	10	LAD29	6	N.C.	57	V_{CC}	36
CLK2	91	LAD3	104	N.C.	58	V_{CC}	55
$\overline{DEN}$	21	LAD30	7	N.C.	59	V_{CC}	56
DT/$\overline{R}$	13	LAD31	8	N.C.	60	V_{CC}	70
$\overline{FAILURE}$	18	LAD4	105	N.C.	61	V_{CC}	71
HLDA/HOLDR	1	LAD5	106	N.C.	62	V_{CC}	82
HOLD/HLDAR	130	LAD6	107	N.C.	63	V_{CC}	83
$\overline{IAC}$/$\overline{INT0}$	85	LAD7	108	N.C.	64	V_{CC}	92
INT1	86	LAD8	109	N.C.	65	V_{SS}	9
INT2/INTR	87	LAD9	110	N.C.	66	V_{SS}	19
$\overline{INT3}$/$\overline{INTA}$	88	$\overline{LOCK}$	20	N.C.	69	V_{SS}	22
LAD0	100	N.C.	23	N.C.	72	V_{SS}	26
LAD1	101	N.C.	24	N.C.	73	V_{SS}	27
LAD10	111	N.C.	25	N.C.	74	V_{SS}	32
LAD11	112	N.C.	28	N.C.	75	V_{SS}	33
LAD12	113	N.C.	31	N.C.	76	V_{SS}	52
LAD13	115	N.C.	34	N.C.	77	V_{SS}	53
LAD14	116	N.C.	37	N.C.	78	V_{SS}	67
LAD15	117	N.C.	38	N.C.	81	V_{SS}	68
LAD16	118	N.C.	39	N.C.	84	V_{SS}	79
LAD17	119	N.C.	40	N.C.	89	V_{SS}	80
LAD18	120	N.C.	41	N.C.	94	V_{SS}	90
LAD19	121	N.C.	42	N.C.	95	V_{SS}	103
LAD2	102	N.C.	43	N.C.	96	V_{SS}	114
LAD20	122	N.C.	44	N.C.	97	V_{SS}	125
LAD21	123	N.C.	45	N.C.	98	W/$\overline{R}$	11

Table 10. 80960KA PGA Package Thermal Characteristics

Thermal Resistance—°C/Watt							
Parameter	Airflow—ft./min (m/sec)						
	0 (0)	50 (0.25)	100 (0.50)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)
θ Junction-to-Case (Case Measured as shown in Figure 26)	2	2	2	2	2	2	2
θ Case-to-Ambient (No Heatsink)	19	18	17	15	12	10	9
θ Case-to-Ambient (with Omnidirectional Heatsink)	16	15	14	12	9	7	6
θ Case-to-Ambient (with Unidirectional) Heatsink)	15	14	13	11	8	6	5



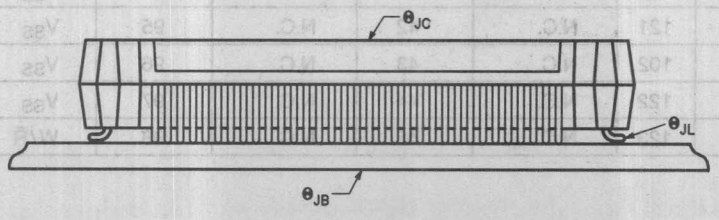
270775-38

NOTES:
1. This table applies to 80960KA PGA plugged into socket or soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. $\theta_{J\text{-}CAP}$ = 4°C/w (approx.)
   $\theta_{J\text{-}PIN}$ = 4°C/w (inner pins) (approx.)
   $\theta_{J\text{-}PIN}$ = 8°C/w (outer pins) (approx.)

Table 11. 80960KA PQFP Package Thermal Characteristics

PQFP Thermal Resistance—°C/Watt							
Parameter	Airflow—ft./min (m/sec)						
	0 (0)	50 (0.25)	100 (0.50)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)
θ Junction-to-Case (Case Measured as shown in Figure 26)	6	6	6	6	6	6	6
θ Case-to-Ambient (No Heatsink)	20	19	18	16	13	11	10

NOTES:
1. This table applies to 80960KA PQFP soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. θ_{JL} = 18°C/Watt
   θ_{JB} = 18°C/Watt



270775-39

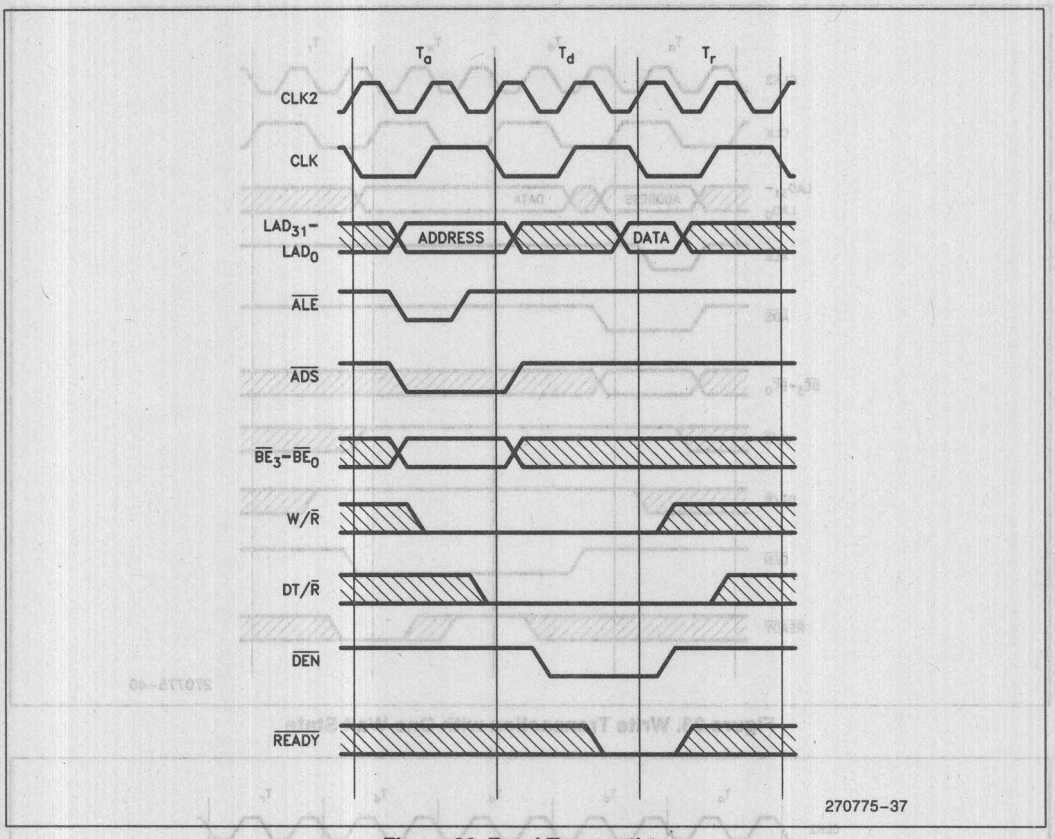


Figure 32. Read Transaction

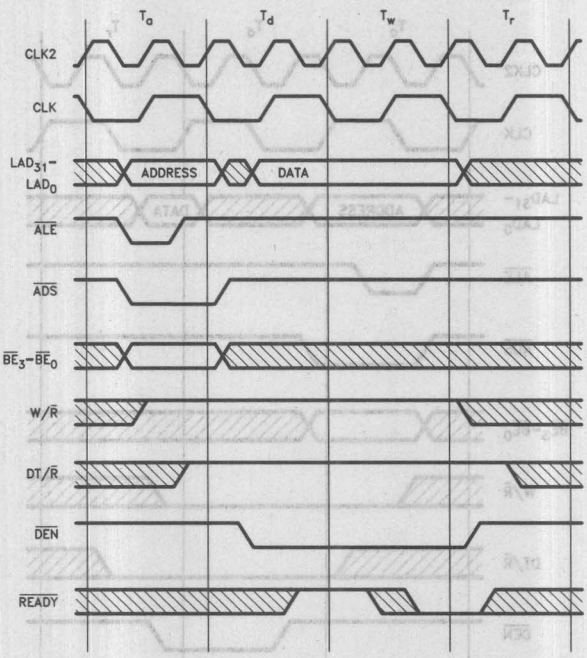


Figure 33. Write Transaction with One Wait State

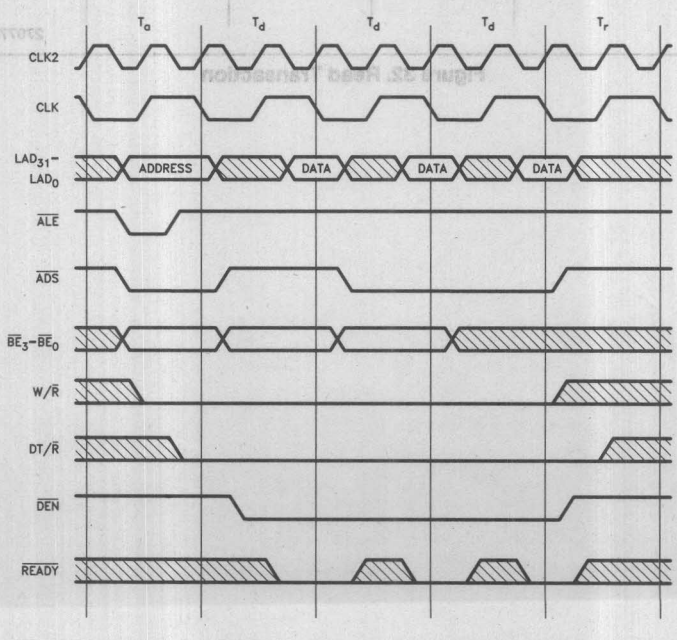


Figure 34. Burst Read Transaction

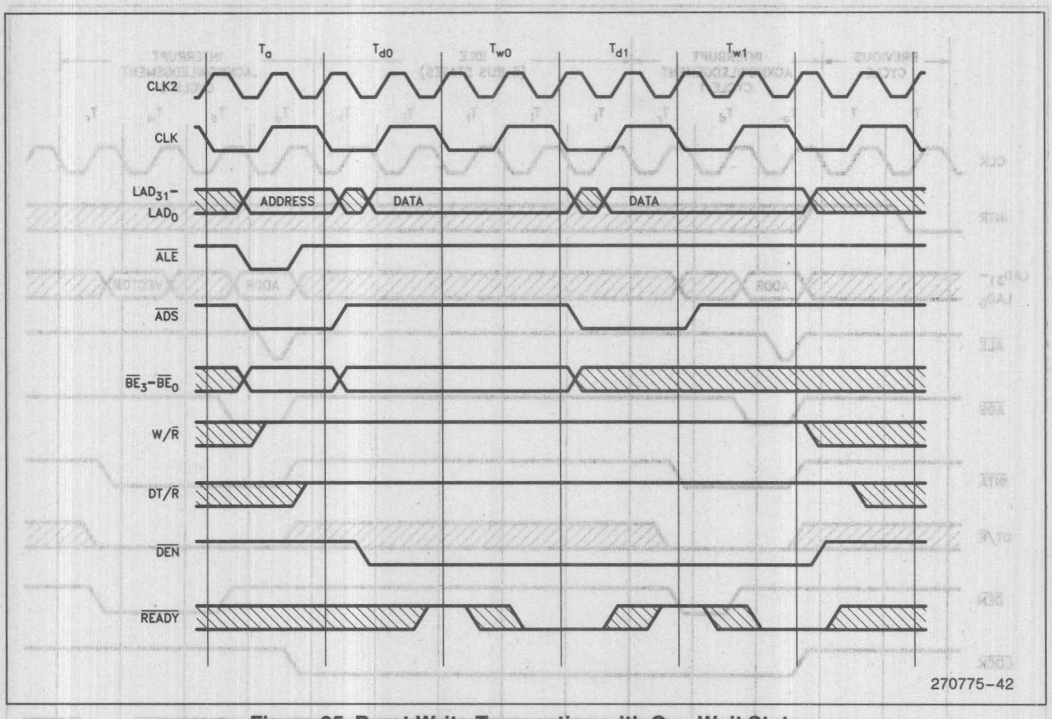
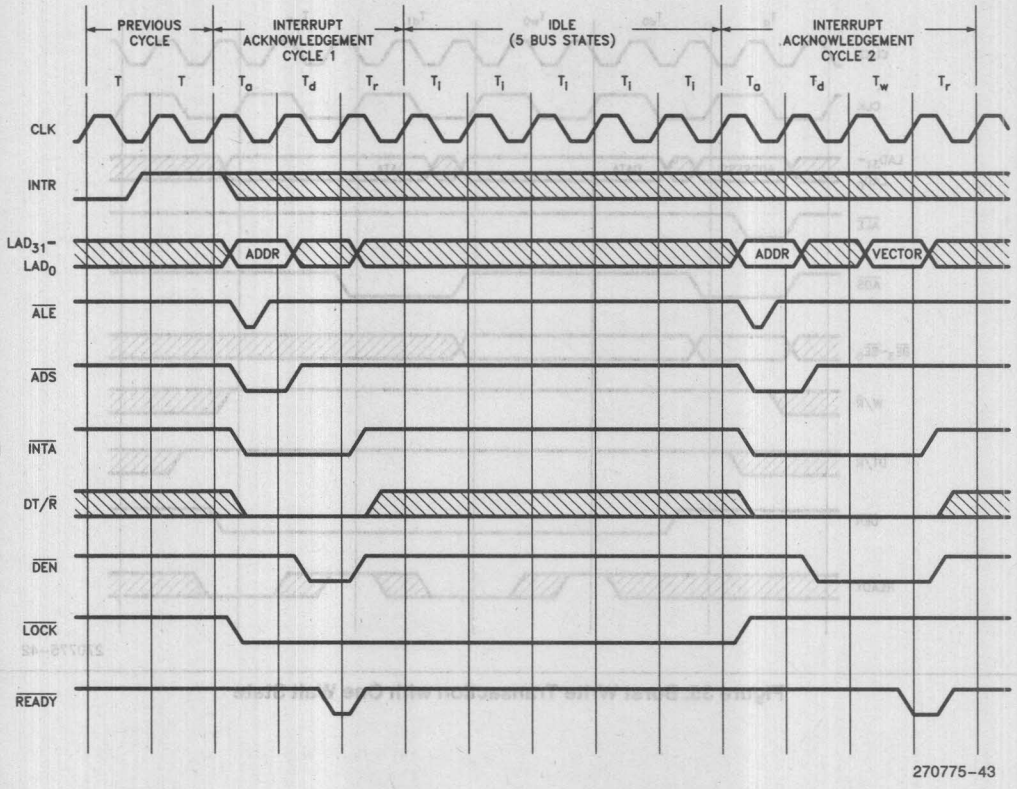


Figure 35. Burst Write Transaction with One Wait State



NOTE:
INTR can go low no sooner than 5 ns (input hold time) following the beginning of interrupt acknowledgement cycle 1. For a second interrupt to be acknowledged, INTR must be low for at least three cycles before it can be reasserted.

Figure 36. Interrupt Acknowledge Transaction

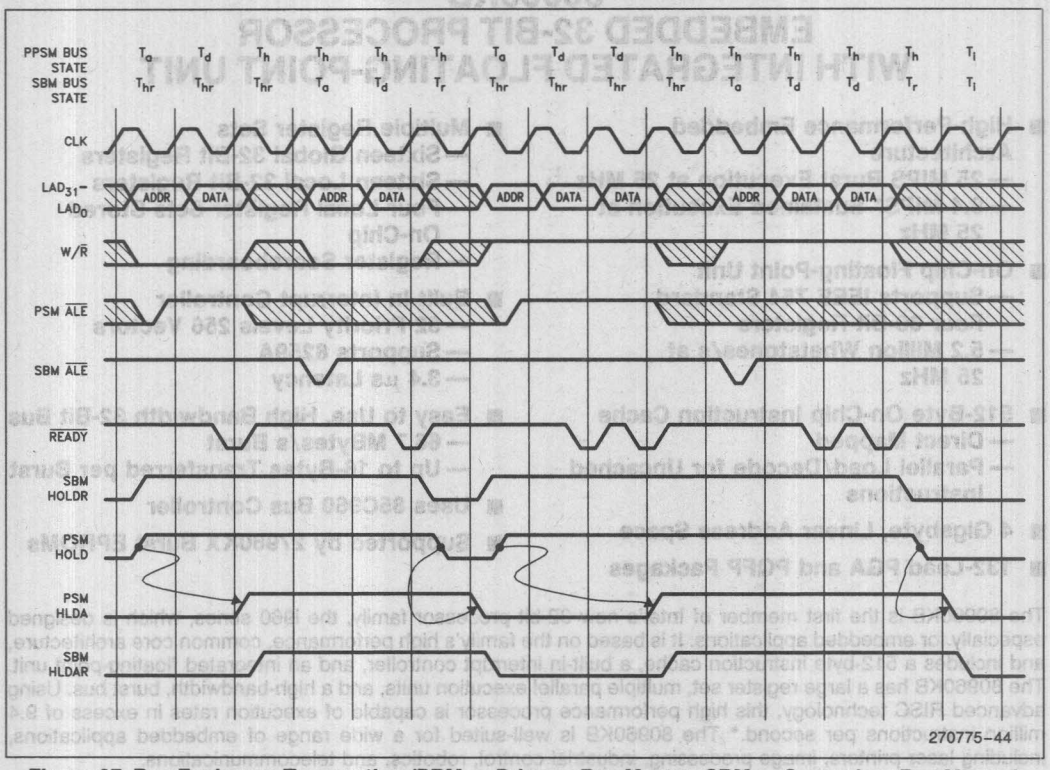


Figure 37. Bus Exchange Transaction (PBM = Primary Bus Master, SBM = Secondary Bus Master)

80960KB
EMBEDDED 32-BIT PROCESSOR WITH INTEGRATED FLOATING-POINT UNIT

- **High-Performance Embedded Architecture**
  - **25 MIPS Burst Execution at 25 MHz**
  - **9.4 MIPS* Sustained Execution at 25 MHz**
- **On-Chip Floating-Point Unit**
  - **Supports IEEE 754 Standard**
  - **Four 80-Bit Registers**
  - **5.2 Million Whetstones/s at 25 MHz**
- **512-Byte On-Chip Instruction Cache**
  - **Direct Mapped**
  - **Parallel Load/Decode for Uncached Instructions**
- **4 Gigabyte, Linear Address Space**
- **132-Lead PGA and PQFP Packages**
- **Multiple Register Sets**
  - **Sixteen Global 32-Bit Registers**
  - **Sixteen Local 32-Bit Registers**
  - **Four Local Register Sets Stored On-Chip**
  - **Register Scoreboarding**
- **Built-In Interrupt Controller**
  - **32 Priority Levels 256 Vectors**
  - **Supports 8259A**
  - **3.4 μs Latency**
- **Easy to Use, High Bandwidth 32-Bit Bus**
  - **66.7 MBytes/s Burst**
  - **Up to 16-Bytes Transferred per Burst**
- **Uses 85C960 Bus Controller**
- **Supported by 27960KX Burst EPROMs**

The 80960KB is the first member of Intel's new 32-bit processor family, the i960 series, which is designed especially for embedded applications. It is based on the family's high performance, common core architecture, and includes a 512-byte instruction cache, a built-in interrupt controller, and an integrated floating-point unit. The 80960KB has a large register set, multiple parallel execution units, and a high-bandwidth, burst bus. Using advanced RISC technology, this high performance processor is capable of execution rates in excess of 9.4 million instructions per second.* The 80960KB is well-suited for a wide range of embedded applications, including laser printers, image processing, industrial control, robotics, and telecommunications.

*Relative to Digital Equipment Corporation's VAX-11/780** at 1 MIPS

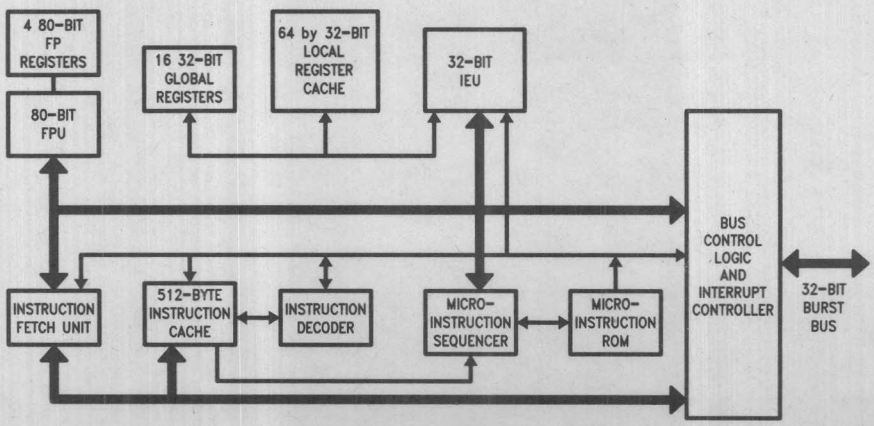


Figure 1. The 80960KB's Highly Parallel Microarchitecture

**VAX-11™ is a trademark of Digital Equipment Corporation.

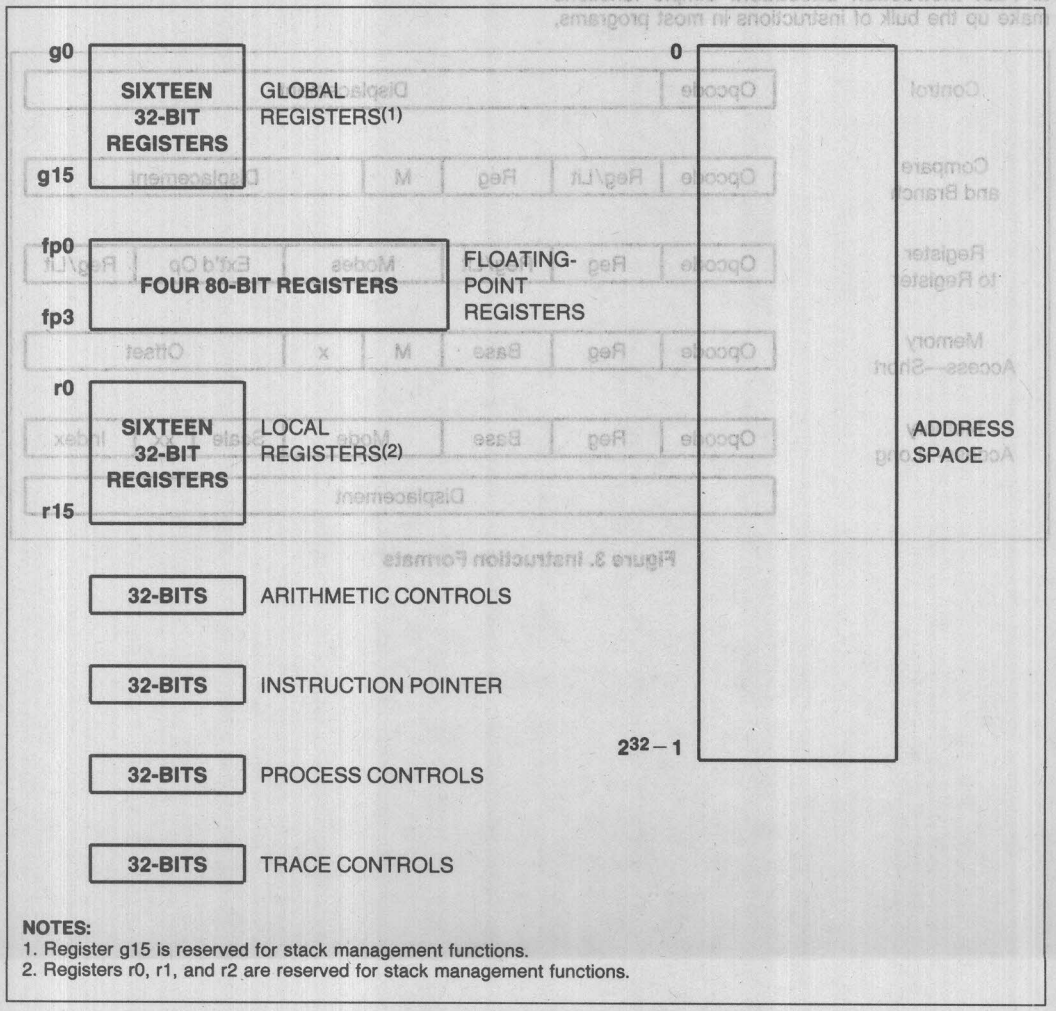
November 1990
Order Number: 270565-005

THE 960 SERIES

The 80960KB is the first member of a new family of 32-bit microprocessors from Intel known as the 960 Series. This series was especially designed to serve the needs of embedded applications. The embedded market includes applications as diverse as industrial automation, avionics, image processing, graphics, robotics, telecommunications, and automobiles. These types of applications require high integration, low power consumption, quick interrupt response times, and high performance. Since time to market is critical, embedded microprocessors need to be easy to use in both hardware and software designs.

All members of the 80960 series share a common core architecture which utilizes RISC technology so that, except for special functions, the family members are object code compatible. Each new processor in the series will add its own special set of functions to the core to satisfy the needs of a specific application or range of applications in the embedded market. For example, future processors may include a DMA controller, a timer, or an A/D converter.

The 80960KB includes an integrated floating-point unit. Intel also offers a pin-compatible version, called the 80960KA, without an FPU, and a military-grade version, the 80960MC, with support for memory management, mutitasking, multiprocessing, and fault tolerance.



NOTES:
1. Register g15 is reserved for stack management functions.
2. Registers r0, r1, and r2 are reserved for stack management functions.

Figure 2. Register Set

KEY PERFORMANCE FEATURES

The 80960KB's architecture is based on the most recent advances in RISC technology and is grounded in Intel's long experience in designing embedded controllers. Many features contribute to the 80960KB's exceptional performance:

1. Large Register Set. Having a large number of registers reduces the number of times that a processor needs to access memory. Modern compilers can take advantage of this feature to optimize execution speed. For maximum flexibility, the 80960KB provides 32 32-bit registers and four 80-bit floating-point registers. (See Figure 2.)

2. Fast Instruction Execution. Simple functions make up the bulk of instructions in most programs, so that execution speed can be greatly improved by ensuring that these core instructions execute in as short a time as possible. The most-frequently executed instructions such as register-register moves, add/subtract, logical operations, and shifts execute in one to two cycles (Table 1 contains a list of instructions.)

3. Load/Store Architecture. Like other processors based on RISC technology, the 80960KB has a Load/Store architecture, only the LOAD and STORE instructions reference memory; all other instructions operate on registers. This type of architecture simplifies instruction decoding and is used in combination with other techniques to increase parallelism.

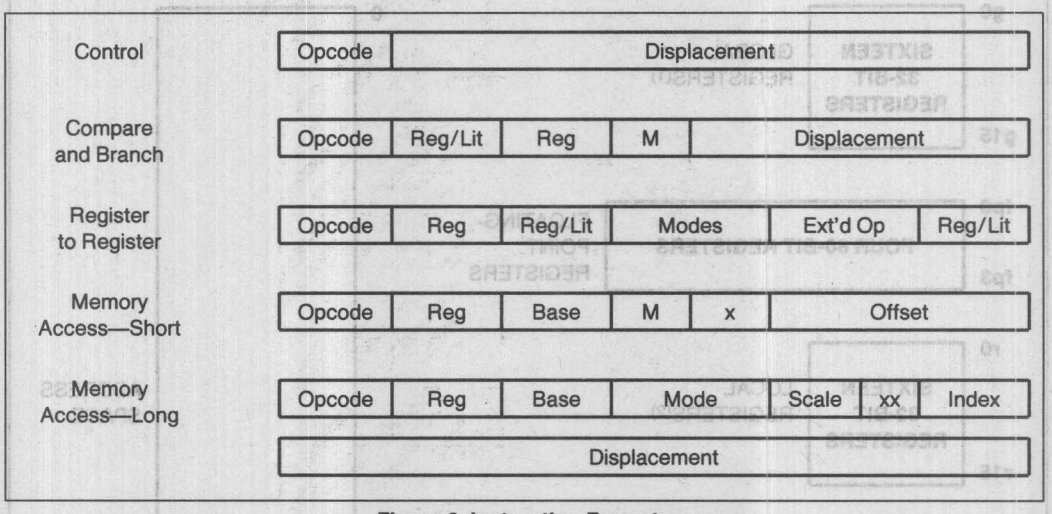


Figure 3. Instruction Formats

Table 1. 80960KB Instruction Set

Data Movement	Arithmetic	Logical	Bit and Bit Field
Load Store Move Load Address	Add Subtract Multiply Divide Remainder Modulo Shift Extended Multiply Extended Divide	And Not And And Not Or Exclusive Or Not Or Or Not Nor Exclusive Nor Not Nand Rotate	Set Bit Clear Bit Not Bit Check Bit Alter Bit Scan for Bit Scan over Bit Extract Modify
Comparison	**Branch**	**Call/Return**	**Fault**
Compare Conditional Compare Compare and Increment Compare and Decrement	Unconditional Branch Conditional Branch Compare and Branch	Call Call Extended Call System Return Branch and Link	Conditional Fault Synchronize Faults
Debug	**Miscellaneous**	**Decimal**	
Modify Trace Controls Mark Force Mark	Atomic Add Atomic Modify Flush Local Registers Modify Arithmetic Controls Modify Process Controls Scan Byte for Equal Test Condition Code	Move Add with Carry Subtract with Carry	
Conversion	**Floating-Point**	**Synchronous**	
Convert Real to Integer Convert Integer to Real	Move Real Add Subtract Multiply Divide Remainder Scale Round Square Root Sine Cosine Tangent Arctangent Log Log Binary Log Natural Exponent Classify Copy Real Extended Compare	Synchronous Load Synchronous Move	

4. Simple Instruction Formats. All instructions in the 80960KB are 32-bits long and must be aligned on word boundaries. This alignment makes it possible to eliminate the instruction-alignment stage in the pipeline. To simplify the instruction decoder further, there are only five instruction formats and each instruction uses only one format. (See Figure 3.)

5. Overlapped Instruction Execution. A load operation allows execution of subsequent instructions to continue before the data has been returned from memory, so that these instructions can overlap the load. The 80960KB manages this process transparently to software through the use of a register scoreboard. Conditional instructions also make use of a scoreboard so that subsequent unrelated instructions can be executed while the conditional instruction is pending.

6. Integer Execution Optimization. When the result of an operation is used as an operand in a subsequent calculation, the value is sent immediately to its destination register. Yet at the same time, the value is put back on a bypass path to the ALU, thereby saving the time that otherwise would be required to retrieve the value for the next operation.

7. Bandwidth Optimizations. The 80960KB gets optimal use of its memory bus bandwidth because the bus is tuned for use with the cache; the line size of the instruction cache matches the maximum burst size for instruction fetches. The 80960KB automatically fetches four words in a burst and stores them directly in the cache. Due to the size of the cache and the fact that it is continually filled in anticipation of needed instructions in the program flow, the 80960KB is exceptionally insensitive to memory wait states. In fact, each wait state causes only a 7% degradation in system perfomance. The benefit is that the 80960KB will deliver outstanding performance even with a low cost memory system.

8. Cache Bypass. If there is a cache miss, the processor fetches the needed instruction, then sends it on to the instruction decoder at the same time it updates the cache. Thus, no extra time is taken to load and read the cache.

Memory Space and Addressing Modes

The 80960KB offers a linear programming environment so that all programs running on the processor are contained in a single address space. The maximum size of the address space is 4 Gigabytes (2^{32} bytes).

For ease of use, the 80960KB has a small number of addressing modes, but includes all those necessary to ensure efficient compiler implementations of high-level languages such as C, Fortran and Ada. Table 2 lists the memory addressing modes.

Data Types

The 80960KB recognizes the following data types:

Numeric:
- 8-, 16-, 32- and 64-bit ordinals
- 8-, 16, 32- and 64-bit integers
- 32-, 64- and 80-bit real numbers

Non-Numeric:
- Bit
- Bit Field
- Triple-Word (96 bits)
- Quad-Word (128 bits)

Large Register Set

The programming environment of the 80960KB includes a large number of registers. In fact, 36 registers are available at any time. The availability of this many registers greatly reduces the number of memory accesses required to execute most programs, which leads to greater instruction processing speed.

There are two types of general-purpose registers: local and global. The 20 global registers consist of sixteen 32-bit registers (G0 through G15) and four 80-bit registers (FP0 through FP3). These registers perform the same function as the general-purpose registers provided in other popular microprocessors. The term global refers to the fact that these registers retain their contents across procedure calls.

The local registers, on the other hand, are procedure specific. For each procedure call, the 80960KB allocates 16 local registers (R0 through R15). Each local register is 32 bits wide. Any register can also be used for single or double-precision floating-point operations; the 80-bit floating-point registers are provided for extended precision.

Multiple Register Sets

To further increase the efficiency of the register set, multiple sets of local registers are stored on-chip. This cache holds up to four local register frames, which means that up to three procedure calls can be made without having to access the procedure stack resident in memory.

Although programs may have procedure calls nested many calls deep, a program typically oscillates back and forth between only two or three levels. As

Table 2. Memory Addressing Modes

- 12-Bit Offset
- 32-Bit Offset
- Register-Indirect
- Register + 12-Bit Offset
- Register + 32-Bit Offset
- Register + (Index-Register × Scale-Factor)
- Register × Scale Factor + 32-Bit Displacement
- Register + (Index-Register × Scale-Factor) + 32-Bit Displacement

Scale-Factor is 1, 2, 4, 8 or 16

a result, with four stack frames in the cache, the probability of there being a free frame on the cache when a call is made is very high. In fact, runs of representative C-language programs show that 80% of the calls are handled without needing to access memory.

If there are four or more active procedures and a new procedure is called, the processor moves the oldest set of local registers in the register cache to a procedure stack in memory to make room for a new set of registers. Global register G15 is used by the processor as the frame pointer (FP) for the procedure stack.

Note that the global and floating-point registers are not exchanged on a procedure call, but retain their contents, making them available to all procedures for fast parameter passing. An illustration of the register cache is shown in Figure 4.

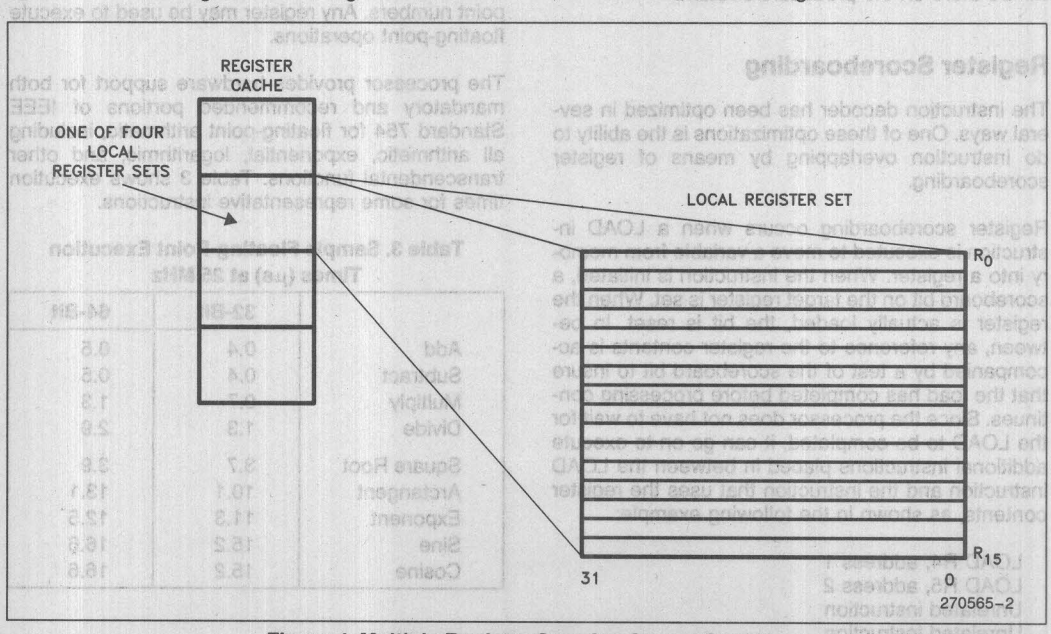


Figure 4. Multiple Register Sets Are Stored On-Chip

Instruction Cache

To further reduce memory accesses, the 80960KB includes a 512-byte on-chip instruction cache. The instruction cache is based on the concept of locality of reference; that is, most programs are not usually executed in a steady stream but consist of many branches and loops that lead to jumping back and forth within the same small section of code. Thus, by maintaining a block of instructions in a cache, the number of memory references required to read instructions into the processor can be greatly reduced.

To load the instruction cache, instructions are fetched in 16-byte blocks, so that up to four instructions can be fetched at one time. An efficient prefetch algorithm increases the probability that an instruction will already be in the cache when it is needed.

Code for small loops will often fit entirely within the cache, leading to a great increase in processing speed since further memory references might not be necessary until the program exits the loop. Similarly, when calling short procedures, the code for the calling procedure is likely to remain in the cache, so it will be there on the procedure's return.

Register Scoreboarding

The instruction decoder has been optimized in several ways. One of these optimizations is the ability to do instruction overlapping by means of register scoreboarding.

Register scoreboarding occurs when a LOAD instruction is executed to move a variable from memory into a register. When the instruction is initiated, a scoreboard bit on the target register is set. When the register is actually loaded, the bit is reset. In between, any reference to the register contents is accompanied by a test of the scoreboard bit to insure that the load has completed before processing continues. Since the processor does not have to wait for the LOAD to be completed, it can go on to execute additional instructions placed in between the LOAD instruction and the instruction that uses the register contents, as shown in the following example:

```
LOAD R4, address 1
LOAD R5, address 2
Unrelated instruction
Unrelated instruction
ADD R4, R5, R6
```

In essence, the two unrelated instructions between the LOAD and ADD instructions are executed for free (i.e., take no apparent time to execute) because they are executed while the register is being loaded. Up to three LOAD instructions can be pending at one time with three corresponding scoreboard bits set. By exploiting this feature, system programmers and compilers have a useful tool for optimizing execution speed.

Floating-Point Arithmetic

In the 80960KB, floating-point arithmetic has been made an integral part of the architecture. Having the floating-point unit integrated on-chip provides two advantages. First, it improves the performance of the chip for floating-point applications, since no additional bus overhead is associated with floating-point calculations, thereby leaving more time for other bus operations such as I/O. Second, the cost of using floating-point operations is reduced because a separate coprocessor chip is not required.

The 80960KB floating-point (real number) data types include single-precision (32-bit), double-precision (64-bit), and extended precision (80-bit) floating-point numbers. Any register may be used to execute floating-point operations.

The processor provides hardware support for both mandatory and recommended portions of IEEE Standard 754 for floating-point arithmetic, including all arithmetic, exponential, logarithmic, and other transcendental functions. Table 3 shows execution times for some representative instructions.

Table 3. Sample Floating-Point Execution Times (μs) at 25 MHz

	32-Bit	64-Bit
Add	0.4	0.5
Subtract	0.4	0.5
Multiply	0.7	1.3
Divide	1.3	2.9
Square Root	3.7	3.9
Arctangent	10.1	13.1
Exponent	11.3	12.5
Sine	15.2	16.6
Cosine	15.2	16.6

High Bandwidth Local Bus

An 80960KB CPU resides on a high-bandwidth address/data bus known as the local bus (L-Bus). The L-Bus provides a direct communication path between the processor and the memory and I/O subsystem interfaces. The processor uses the local bus to fetch instructions, manipulate memory, and respond to interrupts. Its features include:

- 32-bit multiplexed address/data path
- Four-word burst capability, which allows transfers from 1 to 16 bytes at a time
- High bandwidth reads and writes at 66.7 MBytes per second
- Special signal to indicate whether a memory transaction can be cached

Figure 5 identifies the groups of signals which constitute the L-Bus. Table 4 lists the function of the L-Bus and other processor-support signals, such as the interrupt lines.

Interrupt Handling

The 80960KB can be interrupted in one of two ways: by the activation of one of four interrupt pins or by sending a message on the processor's data bus.

The 80960KB is unusual in that it automatically handles interrupts on a priority basis and tracks pending interrupts through its on-chip interrupt controller. Two of the interrupt pins can be configured to provide 8259A handshaking for expansion beyond four interrupt lines.

Debug Features

The 80960KB has built-in debug capabilities. There are two types of breakpoints and six different trace modes. The debug features are controlled by two internal 32-bit registers, the Process-Controls Word and the Trace-Controls Word. By setting bits in these control words, a software debug monitor can closely control how the processor responds during program execution.

The 80960KB has both hardware and software breakpoints. It provides two hardware breakpoint registers on-chip which can be set by a special command to any value. When the instruction pointer matches the value in one of the breakpoint registers, the breakpoint will fire, and a breakpoint handling routine is called automatically.

The 80960KB also provides software breakpoints through the use of two instructions, MARK and FMARK. These instructions can be placed at any point in a program and will cause the processor to halt execution at that point and call the breakpoint handling routine. The breakpoint mechanism is easy to use and provides a powerful debugging tool.

Tracing is available for instructions (single-step execution), calls and returns, and branching. Each different type of trace may be enabled separately by a special debug instruction. In each case, the 80960KB executes the instruction first and then calls a trace handling routine (usually part of a software debug monitor). Further program execution is halted until the trace routine is completed. When the trace event handling routine is completed, instruction execution resumes at the next instruction. The

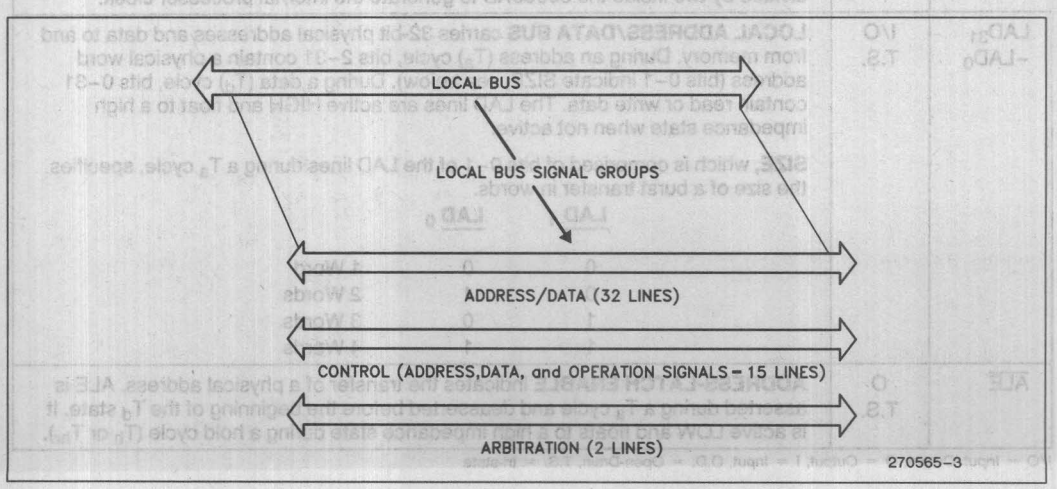


Figure 5. Local Bus Signal Groups

80960KB's tracing mechanisms, which are implemented completely in hardware, greatly simplify the task of testing and debugging software.

FAULT DETECTION

The 80960KB has an automatic mechanism to handle faults. There are ten fault types including trace, arithmetic, and floating-point faults. When the processor detects a fault, it automatically calls the appropriate fault handling routine and saves the current instruction pointer and necessary state information to make efficient recovery possible. The processor posts diagnostic information on the type of fault to a Fault Record. Like interrupt handling routines, fault handling routines are usually written to meet the needs of a specific application and are often included as part of the operating system or kernel.

For each of the ten fault types, there are numerous subtypes that provide specific information about a fault. For example, a floating-point fault may have its subtype set to an Overflow or Zero-Divide fault. The fault handler can use this specific information to respond correctly to the fault.

BUILT-IN TESTABILITY

Upon reset, the 80960KB automatically conducts an extensive internal test (self-test) of its major blocks of logic. Then, before executing its first instruction, it does a zero check sum on the first eight words in memory to ensure that the system has been loaded correctly. If a problem is discovered at any point during the self-test, the 80960KB will assert its FAILURE pin and will not begin program execution. The self-test takes approximately 47,000 cycles to complete.

System manufacturers can use the 80960KB's self-test feature during incoming parts inspection. No special diagnostic programs need to be written, and the test is both thorough and fast. The self-test capability helps ensure that defective parts will be discovered before systems are shipped, and once in the field, the self-test makes it easier to distinguish between problems caused by processor failure and problems resulting from other causes.

CHMOS

The 80960KB is fabricated using Intel's CHMOS IV (Complementary High Speed Metal Oxide Semiconductor) process. This advanced technology eliminates the frequency and reliability limitations of older CMOS processes and opens a new era in microprocessor performance. It combines the high performance capabilities of Intel's industry-leading HMOS technology with the high density and low power characteristics of CMOS. The 80960KB is available at 10, 16, 20 and 25 MHz.

Table 4a. 80960KB Pin Description: L-Bus Signals

Symbol	Type	Name and Function
CLK2	I	**SYSTEM CLOCK** provides the fundamental timing for 80960KB systems. It is divided by two inside the 80960KB to generate the internal processor clock.
LAD_{31} $-LAD_0$	I/O T.S.	**LOCAL ADDRESS/DATA BUS** carries 32-bit physical addresses and data to and from memory. During an address (T_a) cycle, bits 2–31 contain a physical word address (bits 0–1 indicate SIZE; see below). During a data (T_d) cycle, bits 0–31 contain read or write data. The LAD lines are active HIGH and float to a high impedance state when not active. **SIZE,** which is comprised of bits 0–1 of the LAD lines during a T_a cycle, specifies the size of a burst transfer in words. $\underline{LAD}_1$ $\underline{LAD}_0$ 0 0 1 Word 0 1 2 Words 1 0 3 Words 1 1 4 Words
$\overline{ALE}$	O T.S.	**ADDRESS-LATCH ENABLE** indicates the transfer of a physical address. ALE is asserted during a T_a cycle and deasserted before the beginning of the T_d state. It is active LOW and floats to a high impedance state during a hold cycle (T_h or T_{hr}).

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

Table 4a. 80960KB Pin Description: L-Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{ADS}$	O O.D.	**ADDRESS/DATA STATUS** indicates an address state. ADS is asserted every T_a state and deasserted during the the following T_d state. For a burst transaction, $\overline{ADS}$ is asserted again every T_d state where $\overline{READY}$ was asserted in the previous cycle.
W/$\overline{R}$	O O.D.	**WRITE/READ** specifies, during a T_a cycle, whether the operation is a write or read. It is latched on-chip and remains valid during T_d cycles.
DT/$\overline{R}$	O O.D.	**DATA TRANSMIT/RECEIVE** indicates the direction of data transfer to and from the L-Bus. It is low during T_a and T_d cycles for a read or interrupt acknowledgement; it is high during T_a and T_d cycles for a write. $\overline{DT/R}$ never changes state when $\overline{DEN}$ is asserted (see Timing Diagrams).
$\overline{DEN}$	O O.D.	**DATA ENABLE** is asserted during T_d cycles and indicates transfer of data on the LAD bus lines.
$\overline{READY}$	I	**READY** indicates that data on LAD lines can be sampled or removed. If $\overline{READY}$ is not asserted during a T_d cycle, the T_d cycle is extended to the next cycle by inserting a wait state (T_W), and $\overline{ADS}$ is not asserted in the next cycle.
$\overline{LOCK}$	I/O O.D.	**BUS LOCK** prevents other bus masters from gaining control of the L-Bus following the current cycle (if they would assert $\overline{LOCK}$ to do so). $\overline{LOCK}$ is used by the processor or any bus agent when it performs indivisible Read/Modify/Write (RMW) operations. Do not leave $\overline{LOCK}$ unconnected. It must be pulled high for the processor to function properly. For a read that is designated as a RMW-read, $\overline{LOCK}$ is examined. if asserted, the processor waits until it is not asserted; if not asserted, the processor asserts $\overline{LOCK}$ during the T_a cycle and leaves it asserted. A write that is designated as an RMW-write deasserts $\overline{LOCK}$ in the T_a cycle. During the time $\overline{LOCK}$ is asserted, a bus agent can perform a normal read or write but no RMW operations. $\overline{LOCK}$ is also held asserted during an interrupt-acknowledge transaction.
$\overline{BE_3}$–$\overline{BE_0}$	O O.D.	**BYTE ENABLE LINES** specify which data bytes (up to four) on the bus take part in the current bus cycle. $\overline{BE_3}$ corresponds to LAD_{31}–LAD_{24} and $\overline{BE_0}$ corresponds to LAD_7–LAD_0. The byte enables are provided in advance of data. The byte enables asserted during T_a specify the bytes of the first data word. The byte enables asserted during T_d specify the bytes of the next data word (if any), that is, the word to be transmitted following the next assertion of $\overline{READY}$. The byte enables during the T_d cycles preceding the last assertion of $\overline{READY}$ are undefined. The byte enables are latched on-chip and remain constant from one T_d cycle to the next when $\overline{READY}$ is not asserted. For reads, the byte enables specify the byte(s) that the processor will actually use. L-Bus agents are required to assert only adjacent byte enables (e.g., asserting just $\overline{BE_0}$ and $\overline{BE_2}$ is not permitted), and are required to assert at least one byte enable. To produce address bits A_0 and A_1 externally, they can be decoded from the byte enables.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

Table 4a. 80960KB Pin Description: L-Bus Signals (Continued)

Symbol	Type	Name and Function
HOLD/ HLDAR	I	**HOLD:** If the processor is the primary bus master (PBM), the input is interpreted as HOLD, a request from a secondary bus master to acquire the bus. When the processor receives HOLD and grants another master control of the bus, it floats its tri-state bus lines and then asserts HLDA and enters the T_h state. When HOLD is deasserted, the processor will deassert HLDA and go to either the T_i or T_a state. **HOLD ACKNOWLEDGE RECEIVED:** If the processor is a secondary bus master (SBM), the input is HLDAR, which indicates, when HOLDR output is high, that the processor has acquired the bus. Processors and other agents can be told at reset if they are the primary bus master (PBM).
HLDA/ HOLDR	O T.S.	**HOLD ACKNOWLEDGE:** If the processor is a primary bus master, the output is HLDA, which relinquishes control of the bus to another bus master. **HOLD REQUEST:** For secondary bus masters (SBM), the output is HOLDR, which is a request to acquire the bus. The bus is said to be acquired if the agent is a primary bus master and does not have its HLDA output asserted, or if the agent is a secondary bus master and has its HOLD input and HLDA output asserted.
CACHE	O T.S.	**CACHE** indicates if an access is cacheable during a T_a cycle. It is not asserted during any synchronous access, such as a synchronous load or move instruction used for sending an IAC message. The CACHE signal floats to a high impedance state when the processor is idle.

Table 4b. 80960KB Pin Description: Module Support Signals

Symbol	Type	Name and Function
$\overline{\text{BADAC}}$	I	**BAD ACCESS,** if asserted in the cycle following the one in which the last $\overline{\text{READY}}$ of a transaction is asserted, indicates that an unrecoverable error has occurred on the current bus transaction, or that a synchronous load/store instruction has not been acknowledged. **STARTUP:** During system reset, the $\overline{\text{BADAC}}$ signal is interpreted differently. If the signal is high, it indicates that this processor will perform system initialization. If it is low, another processor in the system will perform system initialization instead.
RESET	I	**RESET** clears the internal logic of the processor and causes it to re-initialize. During RESET assertion, the input pins are ignored (except for $\overline{\text{BADAC}}$ and $\overline{\text{IAC}}/\overline{\text{INT}_0}$), the tri-state output pins are placed in a high impedance state, and other output pins are placed in their non-asserted state. RESET must be asserted for at least 41 CLK2 cycles for a predictable RESET. The HIGH to LOW transition of RESET should occur after the rising edge of both CLK2 and the external bus CLK, and before the next rising edge of CLK2.
$\overline{\text{FAILURE}}$	O O.D.	**INITIALIZATION FAILURE** indicates that the processor has failed to initialize correctly. After RESET is deasserted and before the first bus transaction begins, $\overline{\text{FAILURE}}$ is asserted while the processor performs a self-test. If the self-test completes successfully, then $\overline{\text{FAILURE}}$ is deasserted. Next, the processor performs a zero checksum on the first eight words of memory. If it fails, $\overline{\text{FAILURE}}$ is asserted for a second time and remains asserted; if it passes, system initialization continues and $\overline{\text{FAILURE}}$ remains deasserted.
N.C.	N/A	**NOT CONNECTED** indicates pins should not be connected. Never connect any pin marked N.C.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

Table 4b. 80960KB Pin Description: Module Support Signals (Continued)

Symbol	Type	Name and Function
$\overline{IAC}$ $\overline{INT0}$	I	**INTERAGENT COMMUNICATION REQUEST/INTERRUPT 0** indicates either that there is a pending IAC message for the processor or an interrupt. The bus interrupt control register determines in which way the signal should be interpreted. To signal an interrupt or IAC request in a synchronous system, this pin (as well as the other interrupt pins) must be enabled by being deasserted for at least one bus cycle and then asserted for at least one additional bus cycle; in an asynchronous system, the pin must remain deasserted for at least two bus cycles and then be asserted for at least two more bus cycles. **LOCAL PROCESSOR NUMBER:** This signal is interpreted differently during system reset. If the signal is at a high voltage level, it indicates that this processor is a primary bus master (Local Processor Number = 0); if it is at a low voltage level, it indicates that this processor is a secondary bus master (Local Processor Number = 1).
INT1	I	**INTERRUPT 1,** like $\overline{INT0}$, provides direct interrupt signaling.
INT2/ INTR	I	**INTERRUPT 2/INTERRUPT REQUEST:** The bus control registers determines how this pin is interpreted. If INT2, it has the same interpretation as the $\overline{INT0}$ and INT1 pins. If INTR, it is used to receive an interrupt request from an external interrupt controller.
$\overline{INT3}$/ $\overline{INTA}$	I/O O.D.	**INTERRUPT 3/INTERRUPT ACKNOWLEDGE:** The bus interrupt control register determines how this pin is interpreted. If $\overline{INT3}$, it has the same interpretation as the $\overline{INT0}$, INT1, and INT2 pins. If $\overline{INTA}$, it is used as an output to control interrupt-acknowledge bus transactions. The $\overline{INTA}$ output is latched on-chip and remains valid during T_d cycles; as an output, it is open-drain.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = tri-state

ELECTRICAL SPECIFICATIONS

Power and Grounding

The 80960KB is implemented in CHMOS IV technology and has modest power requirements. Its high clock frequency and numerous output buffers (address/data, control, error, and arbitration signals) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 12 V_{CC} and 13 V_{SS} pins separately feed functional units of the 80960KB in the PGA.

Power and ground connections must be made to all power and ground pins of the 80960KB. On the circuit board, all V_{CC} pins must be strapped closely together, preferably on a power plane. Likewise, all V_{SS} pins should be strapped together, preferably on a ground plane. These pins may not be connected together within the chip.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the 80960KB. The processor can cause transient power surges when driving the L-Bus, particularly when it is connected to a large capacitive load.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the processor and decoupling capacitors as much as possible. Capacitors specifically designed for PGA packages are also commercially available and offer the lowest possible inductance.

Connection Recommendations

For reliable operation, always connect unused inputs to an appropriate signal level. In particular, if one or more interrupt lines are not used, they should be pulled up. No inputs should ever be left floating.

All open-drain outputs require a pullup device. While in some cases a simple pullup resistor will be adequate, we recommend a network of pullup and pulldown resistors biased to a valid V_{IH} ($\geq$3.4V) and terminated in the characteristic impedance of the circuit board. Figure 6 shows our recommendations for the resistor values for both a low and high current drive network, which assumes that the circuit board has a characteristic impedance of 100Ω. The advantage of terminating the output signals in this fashion is that it limits signal swing and reduces AC power consumption.

Characteristic Curves

Figure 7 shows the typical supply current requirements over the operating temperature range of the processor at supply voltage (V_{CC}) of 5V. Figure 8 shows the typical power supply current (I_{CC}) required by the 80960KB at various operating frequencies when measured at three input voltage (V_{CC}) levels.

For a given output current (I_{OL}), the curve in Figure 9 shows the worst case output low voltage (V_{OL}).

Figure 10 shows the typical capacitive derating curve for the 80960KB measured from 1.5V on the system clock (CLK) to 1.5V on the falling edge and 1.5V on the rising edge of the L-Bus address/data (LAD) signals.

Test Load Circuit

Figure 13 illustrates the load circuit used to test the 80960KB's tristate pins, and Figure 14 shows the load circuit used to test the open drain outputs. The open drain test uses an active load circuit in the form of a matched diode bridge. Since the open-drain outputs sink current, only the I_{OL} legs of the bridge are necessary and the I_{OH} legs are not used. When the 80960KB driver under test is turned off, the output pin is pulled up to V_{REF} (i.e., V_{OH}). Diode D_1 is turned off and the I_{OL} current source flows through diode D_2.

When the 80960KB open-drain driver under test is on, diode D_1 is also on, and the voltage on the pin being tested drops to V_{OL}. Diode D_2 turns off and I_{OL} flows through diode D_1.

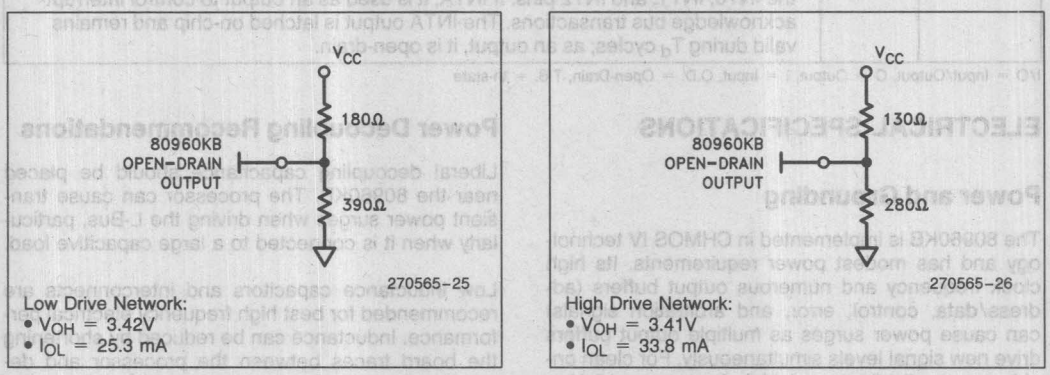


Figure 6. Connection Recommendations for Low and High Current Drive Networks

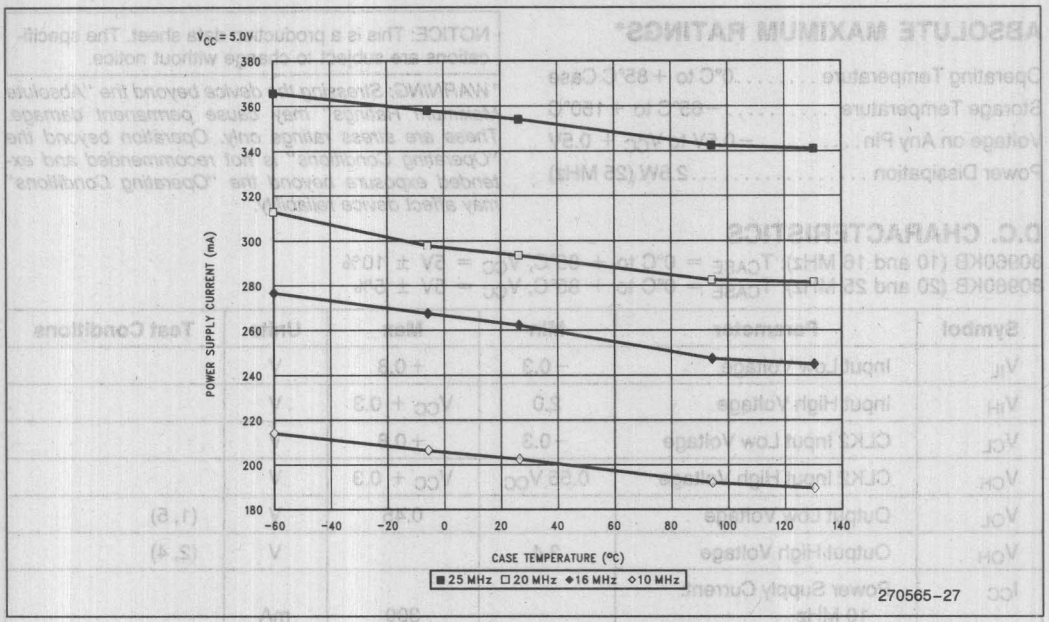


Figure 7. Typical Supply Current (I_{CC})

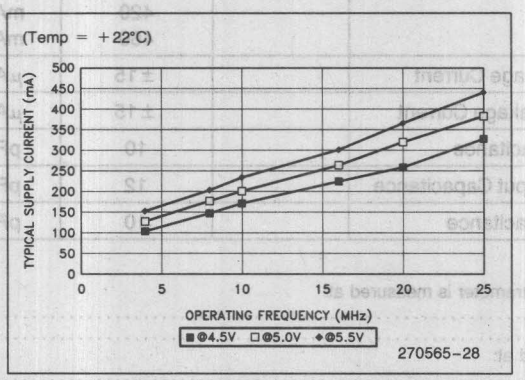


Figure 8. Typical Current vs Frequency

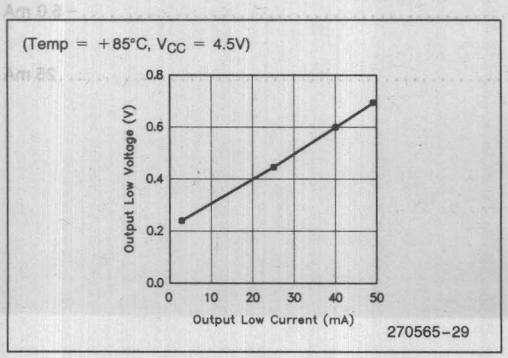


Figure 9. Worst Case Voltage vs Output Current on Open-Drain Pins

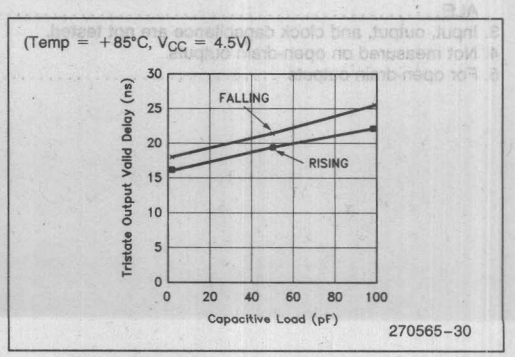


Figure 10. Capacitive Derating Curve

ABSOLUTE MAXIMUM RATINGS*

Operating Temperature . . . . . 0°C to +85°C Case
Storage Temperature . . . . . −65°C to +150°C
Voltage on Any Pin . . . . . −0.5V to V_{CC} + 0.5V
Power Dissipation . . . . . 2.5W (25 MHz)

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

D.C. CHARACTERISTICS

80960KB (10 and 16 MHz): T_{CASE} = 0°C to + 85°C, V_{CC} = 5V ± 10%
80960KB (20 and 25 MHz): T_{CASE} = 0°C to + 85°C, V_{CC} = 5V ± 5%

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+0.8	V	
V_{CH}	CLK2 Input High Voltage	0.55 V_{CC}	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage		0.45	V	(1, 5)
V_{OH}	Output High Voltage	2.4		V	(2, 4)
I_{CC}	Power Supply Current: 10 MHz 16 MHz 20 MHz 25 MHz		 300 375 420 480	 mA mA mA mA	
I_{LI}	Input Leakage Current		±15	µA	$0 \le V_{IN} \le V_{CC}$
I_{LO}	Output Leakage Current		±15	µA	$0.45 \le V_O \le V_{CC}$
C_{IN}	Input Capacitance		10	pF	f_C = 1 MHz(3)
C_O	I/O or Output Capacitance		12	pF	f_C = 1 MHz(3)
C_{CLK}	Clock Capacitance		10	pF	f_C = 1 MHz(3)

NOTES:
1. For tri-state outputs, this parameter is measured at:
   Address/Data . . . . . 4.0 mA
   Controls . . . . . 5.0 mA
2. This parameter is measured at:
   Address/Data . . . . . −1.0 mA
   Controls . . . . . −0.9 mA
   ALE . . . . . −5.0 mA
3. Input, output, and clock capacitance are not tested.
4. Not measured on open-drain outputs.
5. For open-drain outputs . . . . . 25 mA

AC SPECIFICATIONS

This section describes the AC specifications for the 80960KB pins. All input and output timings are specified relative to the 1.5V level of the rising edge. For output timings, the specifications refer to the time it takes the signal to reach 1.5V.

For input timings, the specifications refer to the time at which the signal reaches (for input setup) or leaves (for hold time) the TTL levels of LOW (0.8V) or HIGH (2.0V). All AC testing should be done with input clock voltages of 0.4V and 2.4V, except for the clock (CLK2), which should be tested with input voltages of 0.45 V_{CC} and 0.55 V_{CC}.

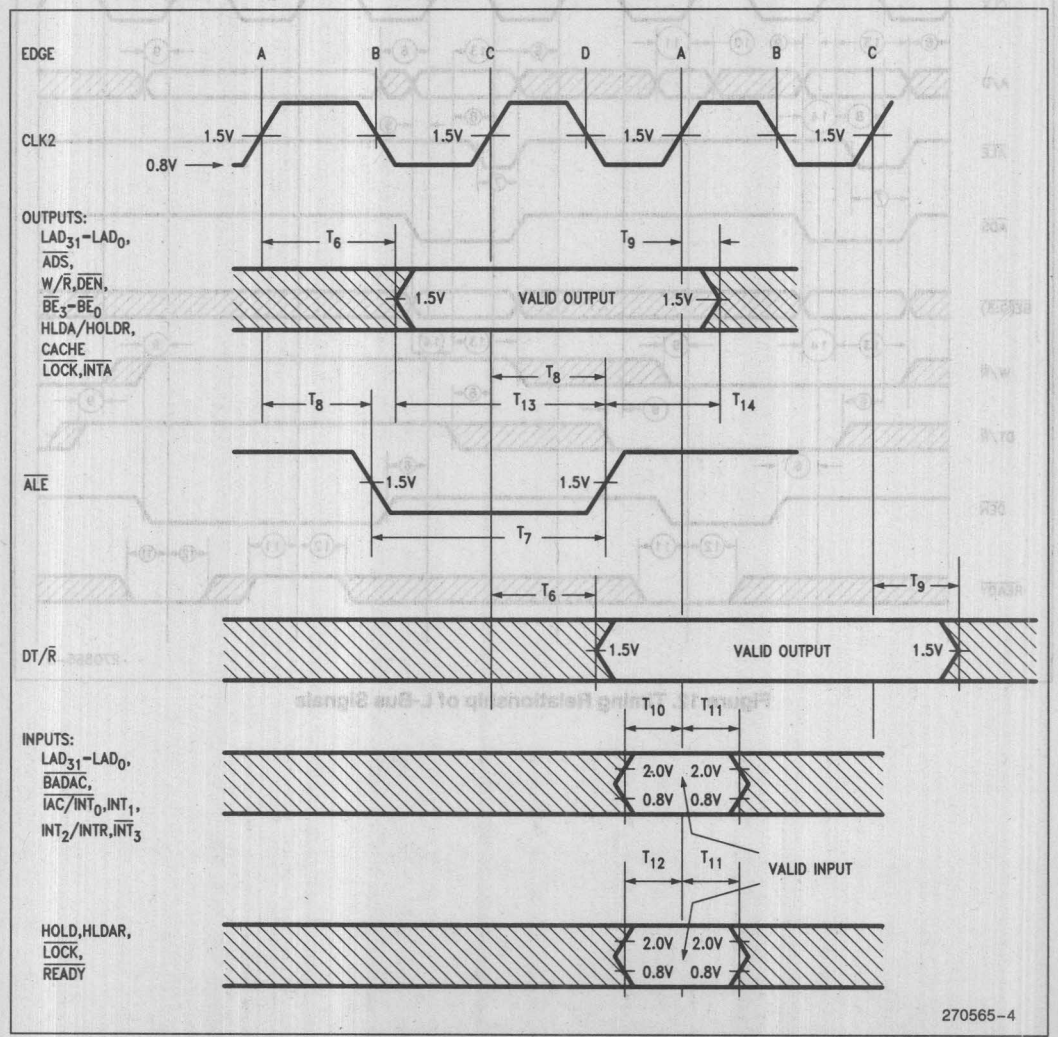


Figure 11. Drive Levels and Timing Relationships for 80960KB Signals

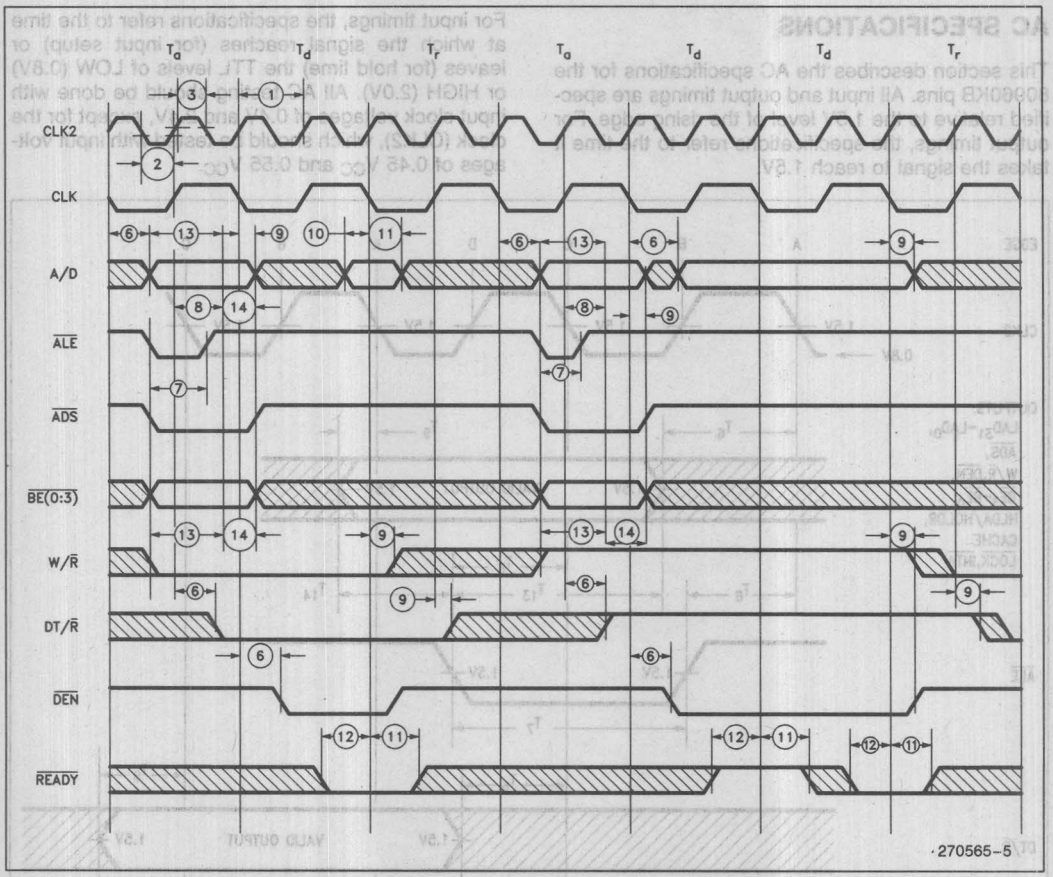


Figure 12. Timing Relationship of L-Bus Signals

A.C. Specification Tables

80960KB A.C. Characteristics (10 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	50	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	12		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	12		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	25	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)(2)
T_{6H}	HOLDA Output Valid Delay	4	31	ns	C_L = 75 pF
T_7	$\overline{ALE}$ Width	25		ns	C_L = 75 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 75 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 75 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	8		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1640		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT_0}$, INT_1, $INT_2/INTR$, $\overline{INT_3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall times are not tested.

3

80960KB A.C. Characteristics (16 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	31.25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	8		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	8		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	25	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	31	ns	C_L = 75 pF
T_7	$\overline{ALE}$ Width	15		ns	C_L = 75 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 75 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)(2)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 75 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	8		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1281		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT_0}$, INT_1, INT_2/INTR, $\overline{INT_3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall times are not tested.

80960KB A.C. Characteristics (20 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	6		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	6		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	26	ns	C_L = 50 pF
T_7	$\overline{ALE}$ Width	12		ns	C_L = 50 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 50 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)(2)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	Input HOLD	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1025		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT}_0$, INT_1, INT_2/INTR, $\overline{INT}_3$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall times are not tested.

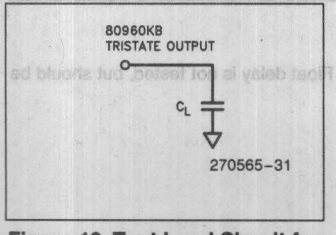


Figure 13. Test Load Circuit for TRI-STATE Output Pins

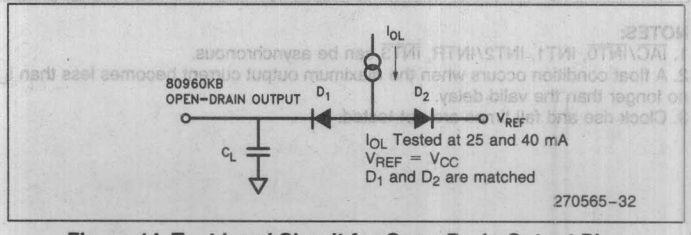


Figure 14. Test Load Circuit for Open-Drain Output Pins

80960KB A.C. Characteristics (25 MHz)

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	20	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	5		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time	5		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	18	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	24	ns	C_L = 50 pF
T_7	$\overline{ALE}$ Width	12		ns	C_L = 50 pF
T_8	$\overline{ALE}$ Output Valid Delay	0	20	ns	C_L = 50 pF (2)
T_9	Output Float Delay	2	18	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	
T_{11}	Input Hold	5		ns	
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	820		ns	41 CLK2 Periods Minimum

NOTES:
1. $\overline{IAC}/\overline{INT0}$, INT1, INT2/INTR, $\overline{INT3}$ can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Clock rise and fall times are not tested.

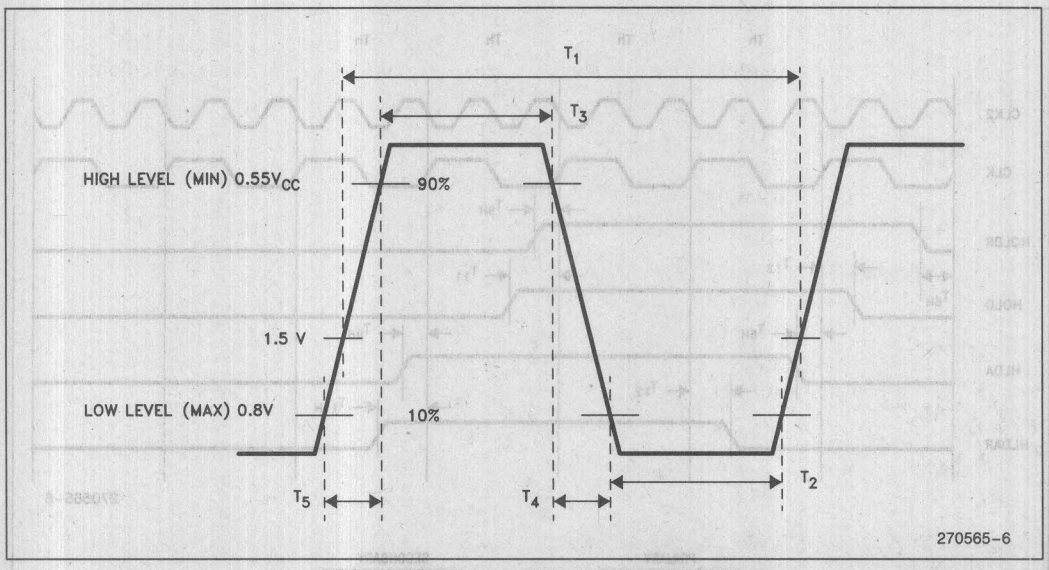


Figure 15. Processor Clock Pulse (CLK2)

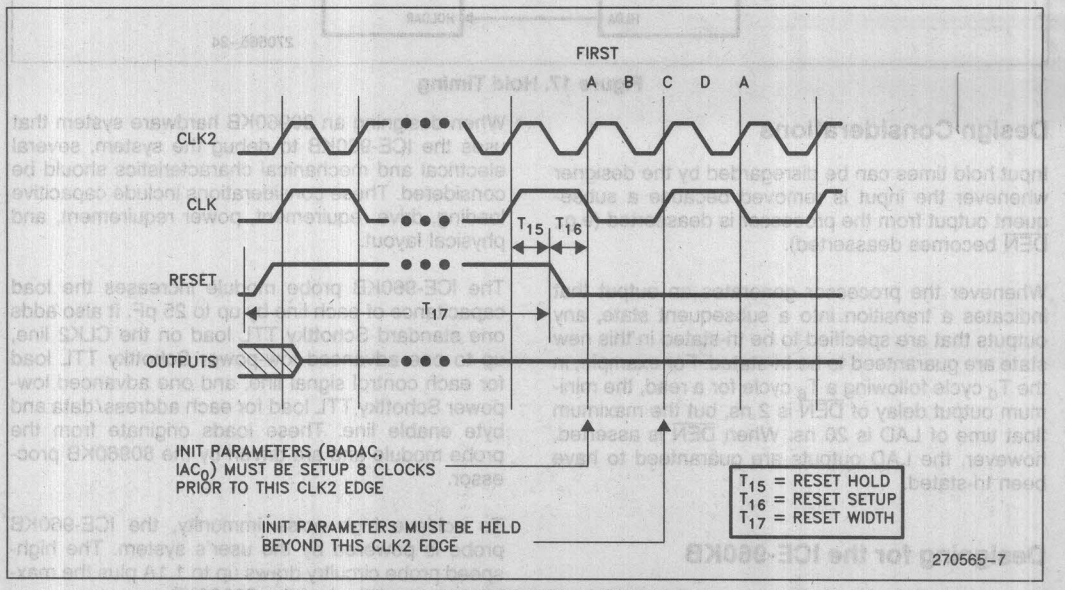


Figure 16. RESET Signal Timing

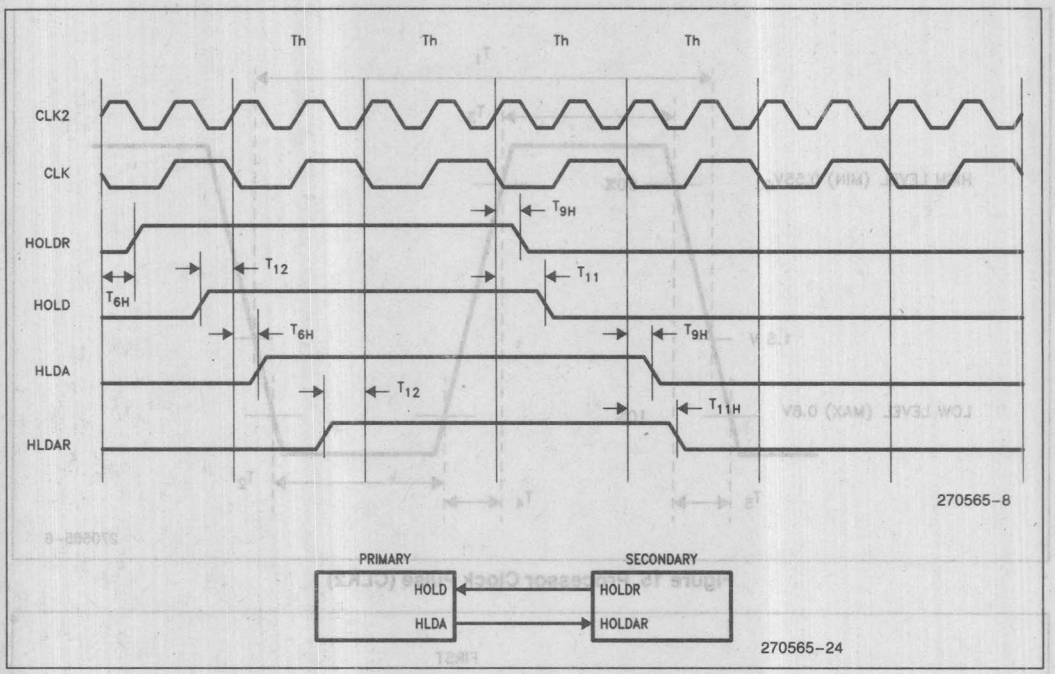


Figure 17. Hold Timing

Design Considerations

Input hold times can be disregarded by the designer whenever the input is removed because a subsequent output from the processor is deasserted (e.g., $\overline{DEN}$ becomes deasserted).

Whenever the processor generates an output that indicates a transition into a subsequent state, any outputs that are specified to be tri-stated in this new state are guaranteed to be tri-stated. For example, in the T_d cycle following a T_a cycle for a read, the minimum output delay of $\overline{DEN}$ is 2 ns, but the maximum float time of LAD is 20 ns. When $\overline{DEN}$ is asserted, however, the LAD outputs are guaranteed to have been tri-stated.

Designing for the ICE-960KB

The 80960KB In-Circuit Emulator assists in debugging both 80960KA and 80960KB hardware and software designs. The product consists of a probe module, cable, and control unit. Because of the high operating frequency of 80960KB systems, the probe module connects directly to the 80960KB socket.

When designing an 80960KB hardware system that uses the ICE-960KB to debug the system, several electrical and mechanical characteristics should be considered. These considerations include capacitive loading, drive requirement, power requirement, and physical layout.

The ICE-960KB probe module increases the load capacitance of each line by up to 25 pF. It also adds one standard Schottky TTL load on the CLK2 line, up to one advanced low-power Schottky TTL load for each control signal line, and one advanced low-power Schottky TTL load for each address/data and byte enable line. These loads originate from the probe module and are driven by the 80960KB processor.

To achieve high noise immunity, the ICE-960KB probe is powered by the user's system. The high-speed probe circuitry draws up to 1.1A plus the maximum current (I_{CC}) of the 80960KB processor.

The mechanical considerations are shown in Figure 18, which illustrates the lateral clearance requirements for the ICE-960KB probe as viewed from above the socket of the 80960KB processor.

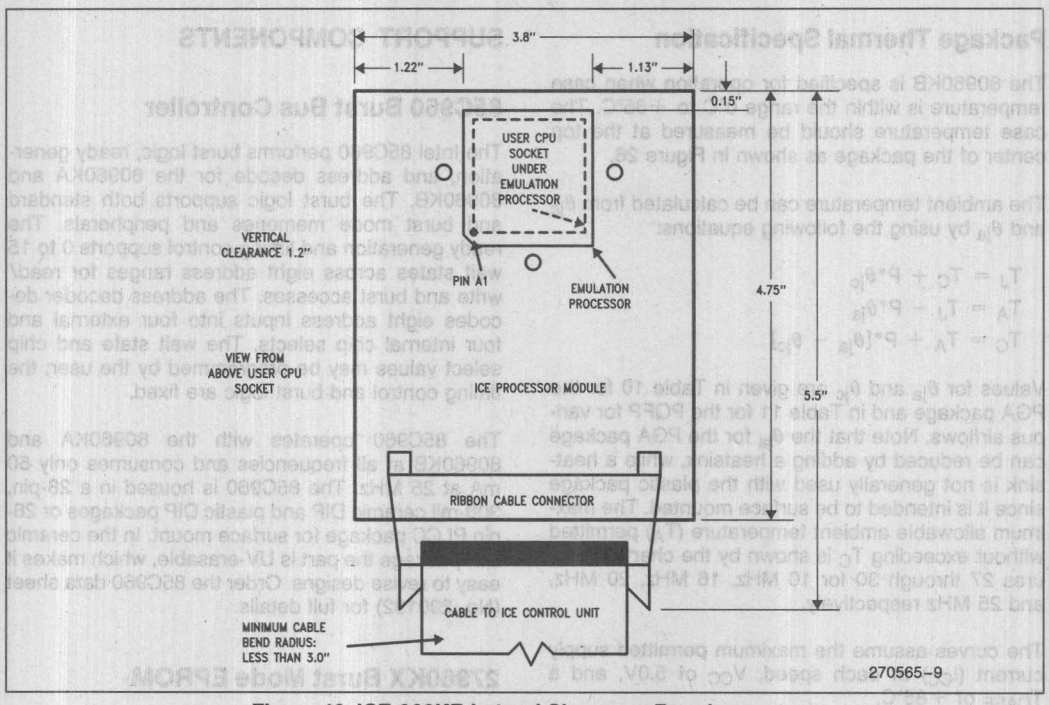


Figure 18. ICE-960KB Lateral Clearance Requirements

MECHANICAL DATA

Package Dimensions and Mounting

The 80960KB is available in two different packages: a 132-lead ceramic pin-grid array (PGA) and a 132-lead plastic quad flat pack (PQFP). Pins in the ceramic package are arranged 0.100 inch (2.54 mm) center-to-center, in a 14 by 14 matrix, three rows around. (See Figure 19.) The plastic package uses fine-pitch gull wing leads arranged in a single row along the perimeter of the package with 0.025 inch (0.64 mm) spacing. (See Figure 20.) Dimensions are given in Figure 21 and Table 7.

There are a wide variety of sockets available for the ceramic PGA package including low-insertion or zero-insertion force mountings, and a choice of terminals such as soldertail, surface mount, or wire wrap. Several applicable sockets are shown in Figure 22.

The PQFP is normally surface mounted to take best advantage of the plastic package's small footprint and low cost. In some applications, however, designers may prefer to use a socket, either to improve heat dissipation or reduce repair costs. Figures 23a and 23b show two of the many sockets available.

Pin Assignment

The PGA and PQFP have different pin assignments. Figure 24 shows the view from the bottom of the PGA (pins facing up) and Figure 25 shows a view from the top of the PGA (pins facing down). Figures 20 and 32 show the top view of the PQFP; notice that the pins are numbered in order from 1 to 132 around the package's perimeter. Tables 5 and 6 list the function of each pin in the PGA, and Tables 8 and 9 list the function of each pin in the PQFP.

V_{CC} and GND connections must be made to multiple V_{CC} and GND pins. Each V_{CC} and GND pin must be connected to the appropriate voltage or ground and externally strapped close to the package. We recommend that you include separate power and ground planes in your circuit board for power distribution.

NOTE:
Pins identified as N.C., "No Connect," should never be connected. The 80960KB PGA and PQFP packages both contain 53 N.C. pins.

Package Thermal Specification

The 80960KB is specified for operation when case temperature is within the range 0°C to +85°C. The case temperature should be measured at the top center of the package as shown in Figure 26.

The ambient temperature can be calculated from θ_{jc} and θ_{ja} by using the following equations:

$$T_J = T_C + P^*\theta_{jc}$$
$$T_A = T_J - P^*\theta_{ja}$$
$$T_C = T_A + P^*[\theta_{ja} - \theta_{jc}]$$

Values for θ_{ja} and θ_{jc} are given in Table 10 for the PGA package and in Table 11 for the PQFP for various airflows. Note that the θ_{ja} for the PGA package can be reduced by adding a heatsink, while a heatsink is not generally used with the plastic package since it is intended to be surface mounted. The maximum allowable ambient temperature (T_A) permitted without exceeding T_C is shown by the charts in Figures 27 through 30 for 10 MHz, 16 MHz, 20 MHz, and 25 MHz respectively.

The curves assume the maximum permitted supply current (I_{CC}) at each speed, V_{CC} of 5.0V, and a T_{CASE} of +85°C.

If you will be using the 80960KB in a harsh environment where the ambient temperature may exceed the limits for the normal commercial part, you should consider using an extended temperature part. These parts are designed by the prefix "TA" and are available at 10, 16 and 20 MHz in the ceramic PGA package. Figure 30 shows the maximum allowable ambient temperature for the 20 MHz extended temperature TA80960KB at various airflows. The curve assumes an I_{CC} of 420 mA, V_{CC} of 5.0V, and a T_{CASE} of +125°C.

WAVEFORMS

Figures 32 through 37 show the waveforms for various transactions on the 80960KB's local bus.

SUPPORT COMPONENTS

85C960 Burst Bus Controller

The Intel 85C960 performs burst logic, ready generation, and address decode for the 80960KA and 80960KB. The burst logic supports both standard and burst mode memories and peripherals. The ready generation and timing control supports 0 to 15 wait states across eight address ranges for read/write and burst accesses. The address decoder decodes eight address inputs into four external and four internal chip selects. The wait state and chip select values may be programmed by the user; the timing control and burst logic are fixed.

The 85C960 operates with the 80960KA and 80960KB at all frequencies and consumes only 50 mA at 25 MHz. The 85C960 is housed in a 28-pin, 300-mil ceramic DIP and plastic DIP packages or 28-pin PLCC package for surface mount. In the ceramic DIP package the part is UV-erasable, which makes it easy to revise designs. Order the 85C960 data sheet (No. 290192) for full details.

27960KX Burst Mode EPROM

Intel 27960KX one-megabit EPROM is designed specifically to support the 80960KA and 80960KB. It uses a burst interface to offer near zero wait-state performance without the high cost of alternative memory technologies. The 27960KX removes the need for "dumping" code and data stored in slow EPROMs or ROMs into expensive high-speed "shadow" RAM.

Internally, the 27960KX is organized in blocks of four bytes that are accessed sequentially. The address of the four-byte block is latched and incremented internally. After a set number of wait-states (1 or 2), data is output one word at a time each subsequent clock cycle. High-performance outputs provide zero wait-state data-to-data burst accesses. Extra power and ground pins dedicated to the output reduce the effect of fast output switching on the device. The 27960KX offers 1-0-0-0 performance at 20 MHz and 2-0-0-0 performance at 25 MHz. Full details can be found in the 27960KX data sheet (No. 290337).

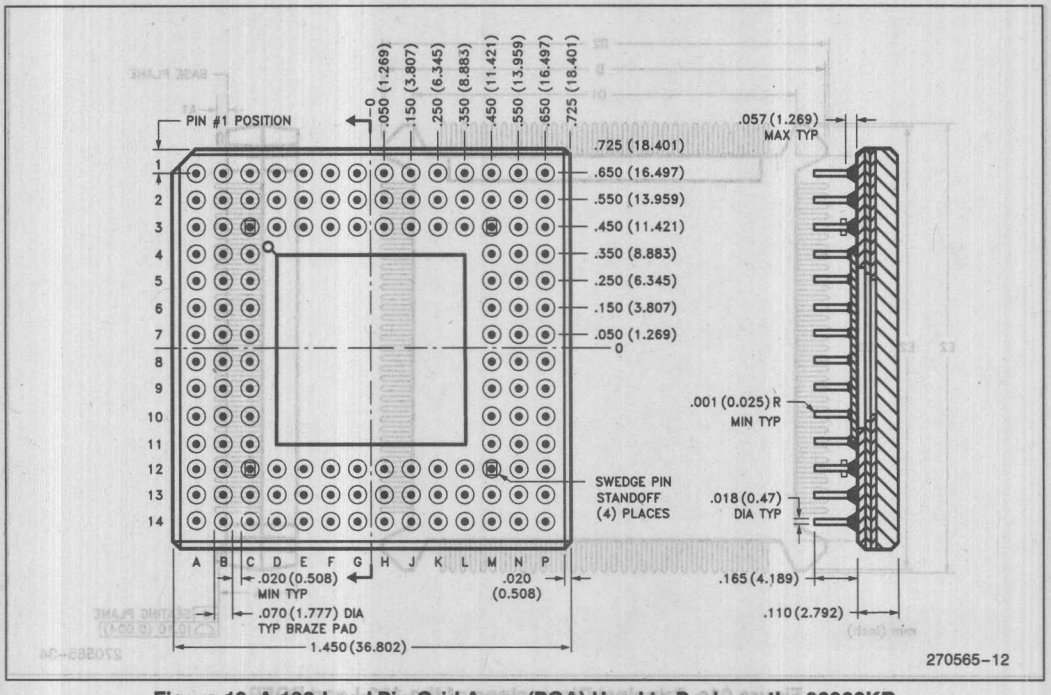


Figure 19. A 132-Lead Pin-Grid Array (PGA) Used to Package the 80960KB

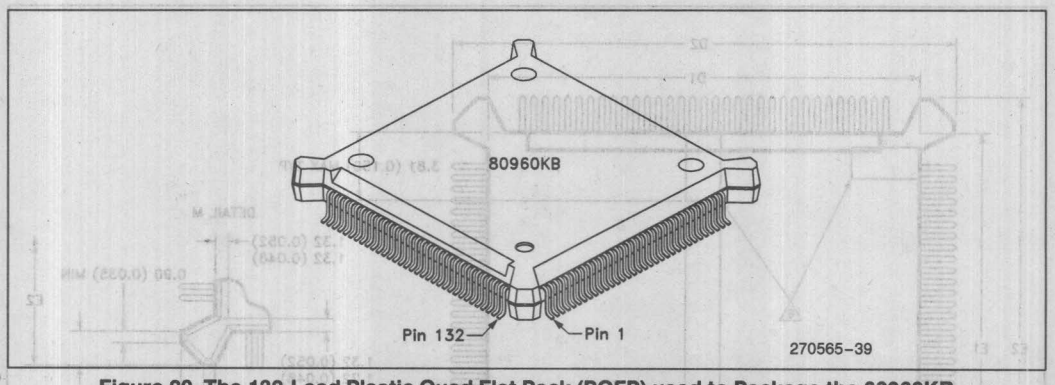


Figure 20. The 132-Lead Plastic Quad Flat Pack (PQFP) used to Package the 80960KB

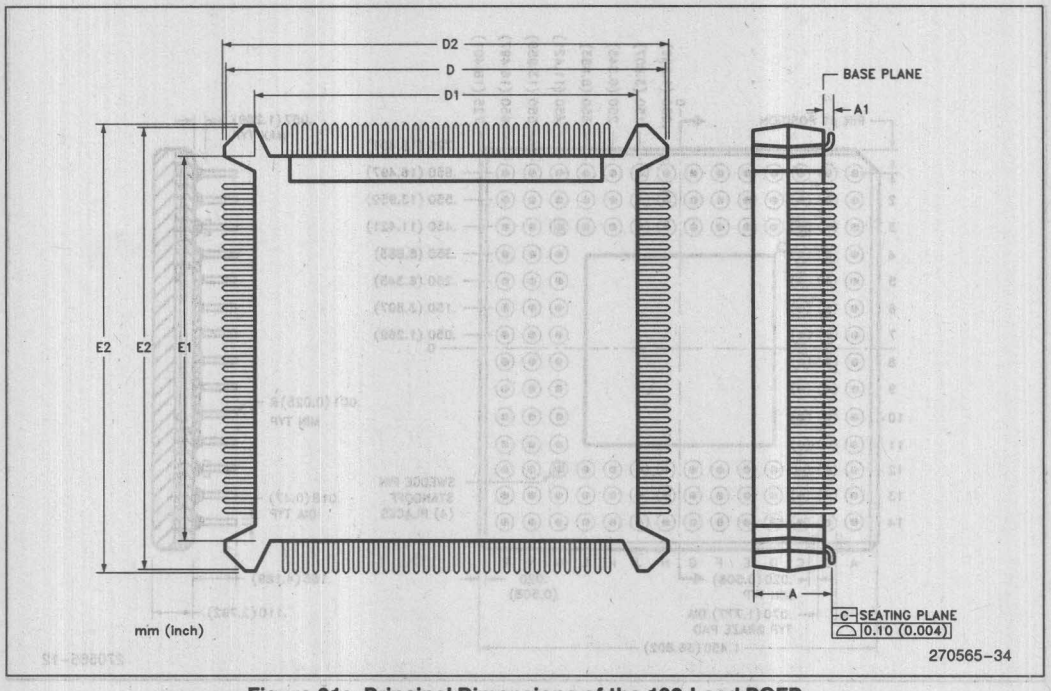


Figure 21a. Principal Dimensions of the 132-Lead PQFP

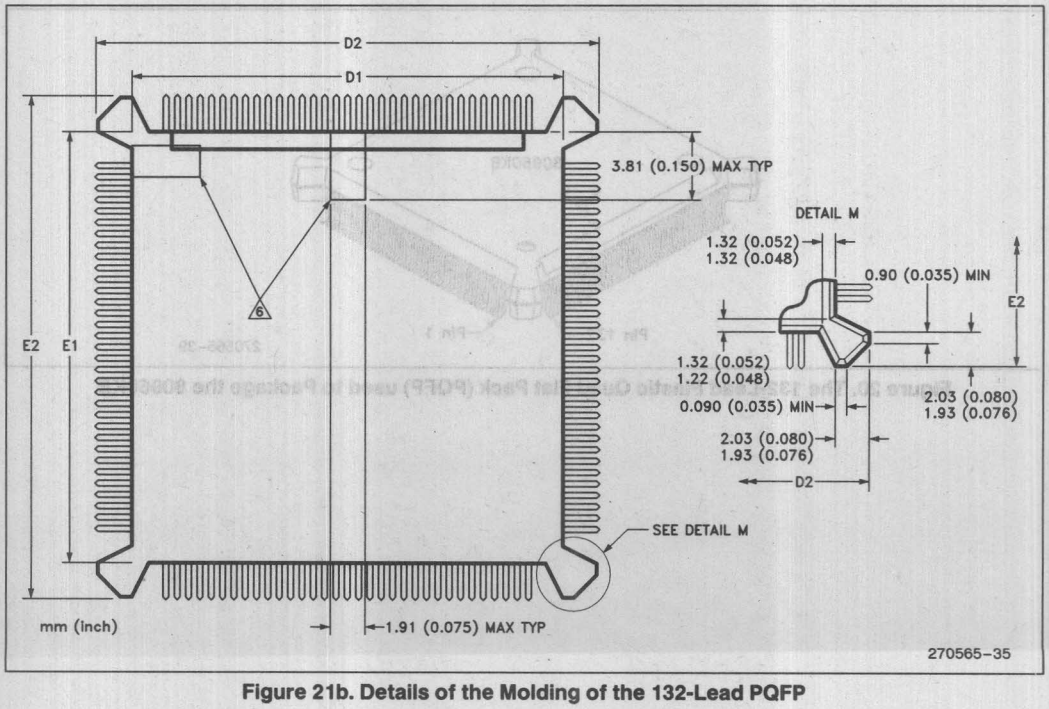


Figure 21b. Details of the Molding of the 132-Lead PQFP

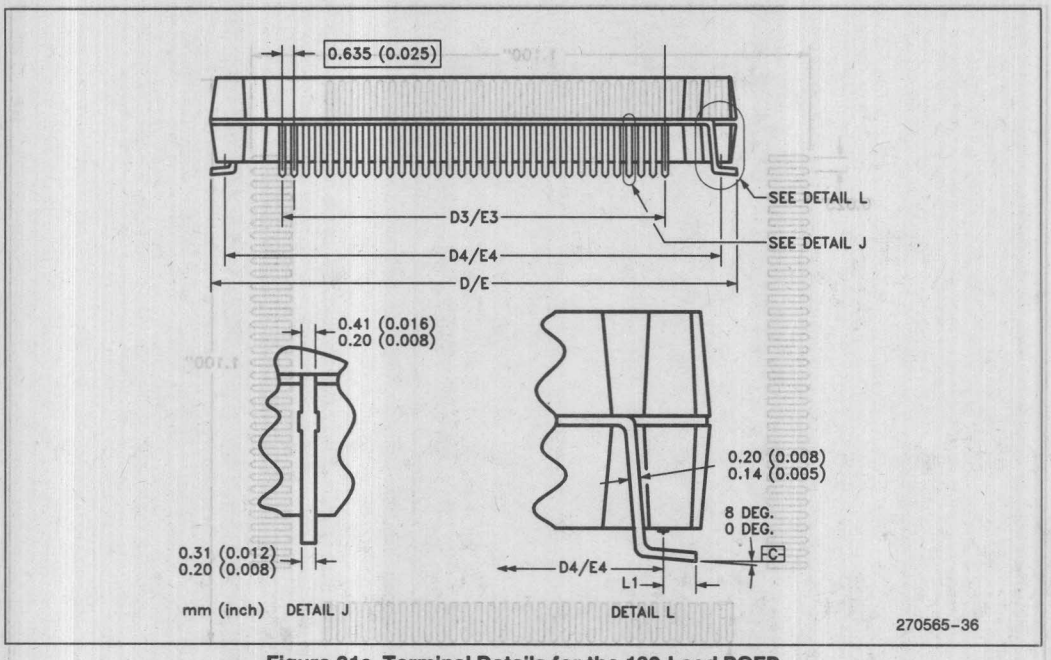


Figure 21c. Terminal Details for the 132-Lead PQFP

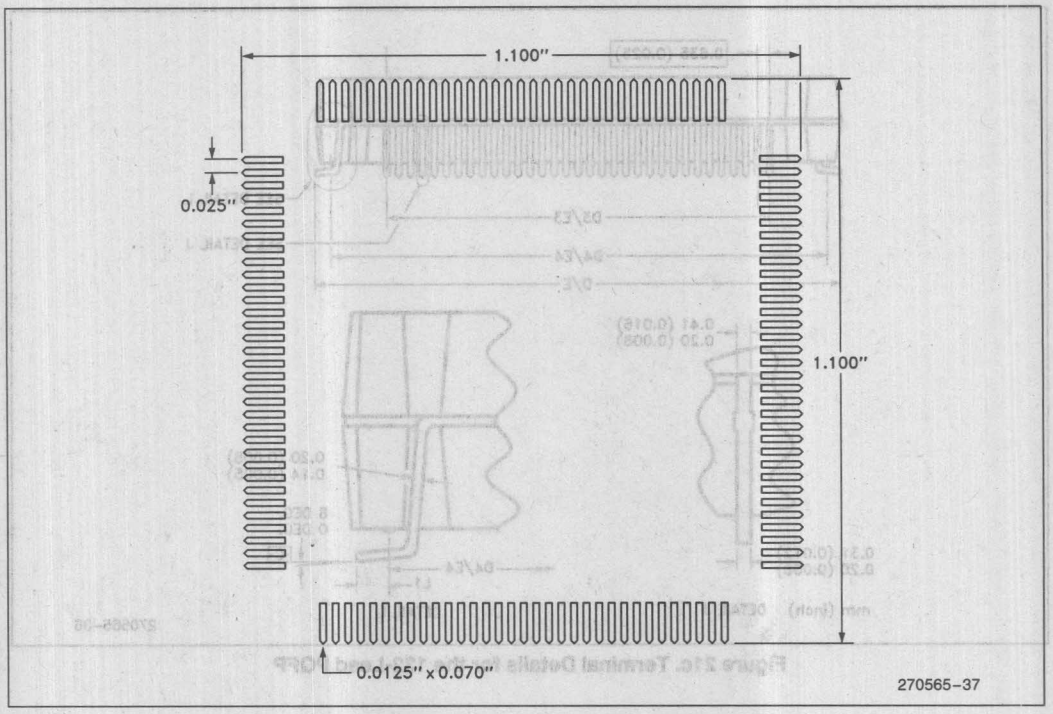


Figure 21d. Board Footprint Area for the 132-Lead PQFP

Table 7. Package Dimension: 80960KB PQFP

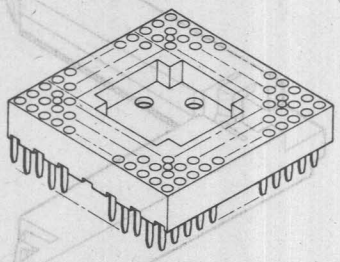
Symbol	Description	Inches		MM	
		Min	Max	Min	Max
N	Leadcount	132 Leads		132 Leads	
A	Package Height	0.160	0.170	4.060	4.320
A1	Standoff	0.020	0.030	0.510	0.760
D,E	Terminal Dimension	1.075	1.085	27.310	27.560
D1,E1	Package Body	0.947	0.953	24.050	24.210
D2,E2	Bumper Distance Without Flash With Flash	 1.097 1.097	 1.103 1.110	 27.860 27.860	 28.010 28.190
D3,E3	Lead Dimension	0.800 REF		20.32 REF	
D4,E4	Foot Radius Location	1.023	1.037	25.890	26.330
L1	Foot Length	0.020	0.030	0.510	0.760

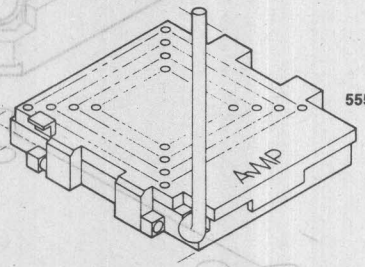
- Low insertion force (LIF) soldertail 55274-1
- Amp tests indicate 50% reduction in insertion force compared to machined sockets

Other socket options

- Zero insertion force (ZIF) soldertail 55583-1
- Zero insertion force (ZIF) Burn-in version 55573-2

Amp Incorporated
(Harrisburg, PA 17105 U.S.A
Phone 717-564-0100)





270565-13

Cam handle locks in low profile position when 80960KB is installed (handle UP for open and DOWN for closed positions).

Courtesy Amp Incorporated

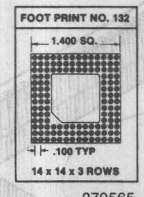
Peel-A-Way* Mylar and Kapton Socket Terminal Carriers

- Low insertion force surface mount CS132-37TG
- Low insertion force soldertail CS132-01TG
- Low insertion force wire-wrap CS132-02TG (two-level) CS132-03TG (thee-level)
- Low insertion force press-fit CS132-05TG

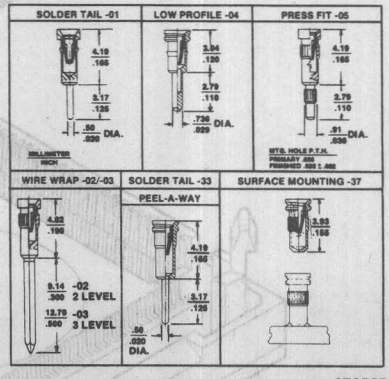
Advanced Interconnections
(5 Division Street)
Warwick, RI 02818 U.S.A.
Phone 401-885-0485)

Peel-A-Way Carrier No. 132:
Kapton Carrier is KS132
Mylar Carrier is MS132

Molded Plastic Body KS132 is shown below:



270565-14



270565-15

Courtesy Advanced Interconnections
(Peel-A-Way Terminal Carriers
U.S. Patent No. 4442938)

*Peel-A-Way is a trademark of Advanced Interconnections.

Figure 22. Several Socket Options for Mounting the 80960KB

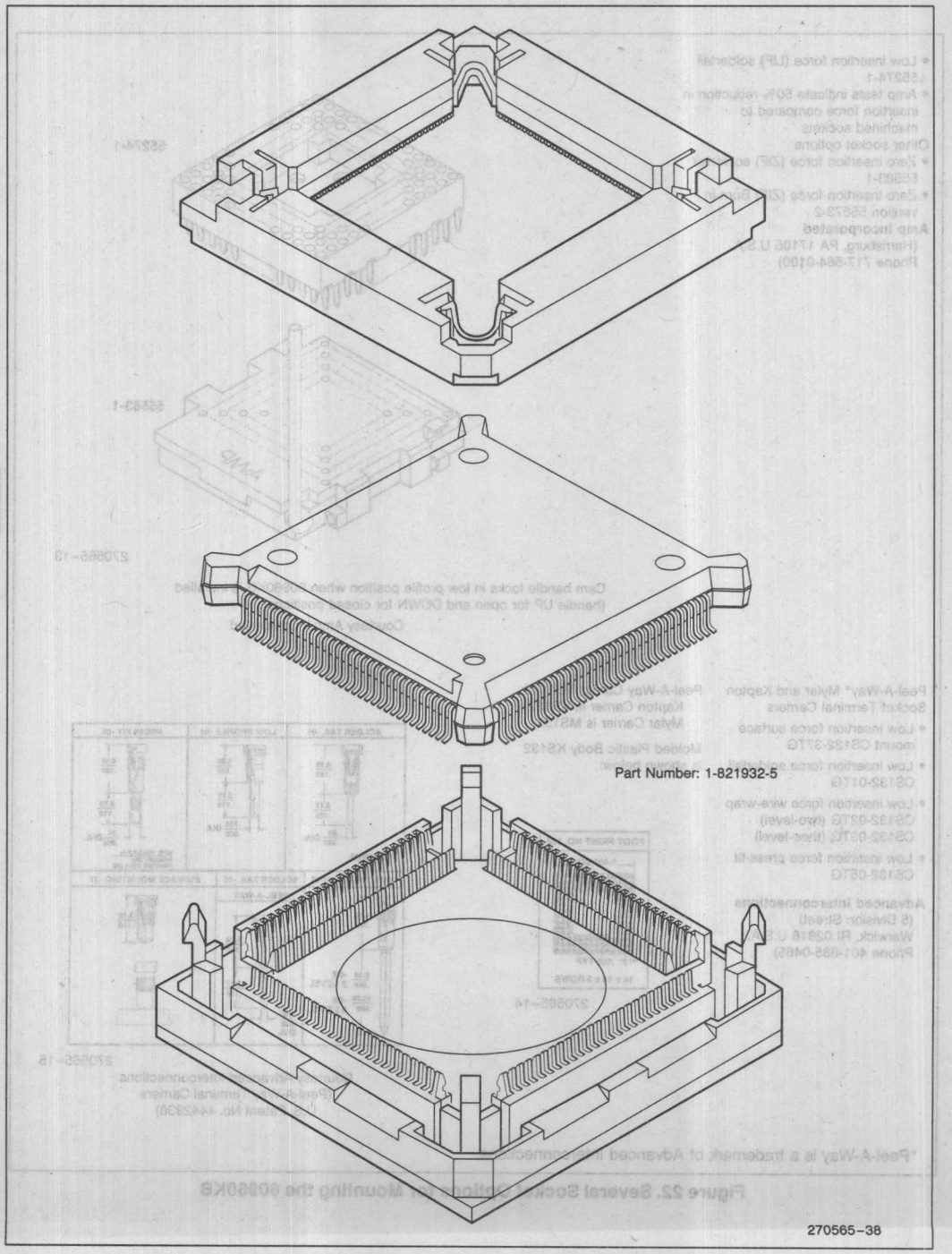


Figure 23a. AMP Micropitch Socket for the 132-Lead Plastic Quad Flat Pack, 0.025" Lead Spacing, Gull Wing Leads

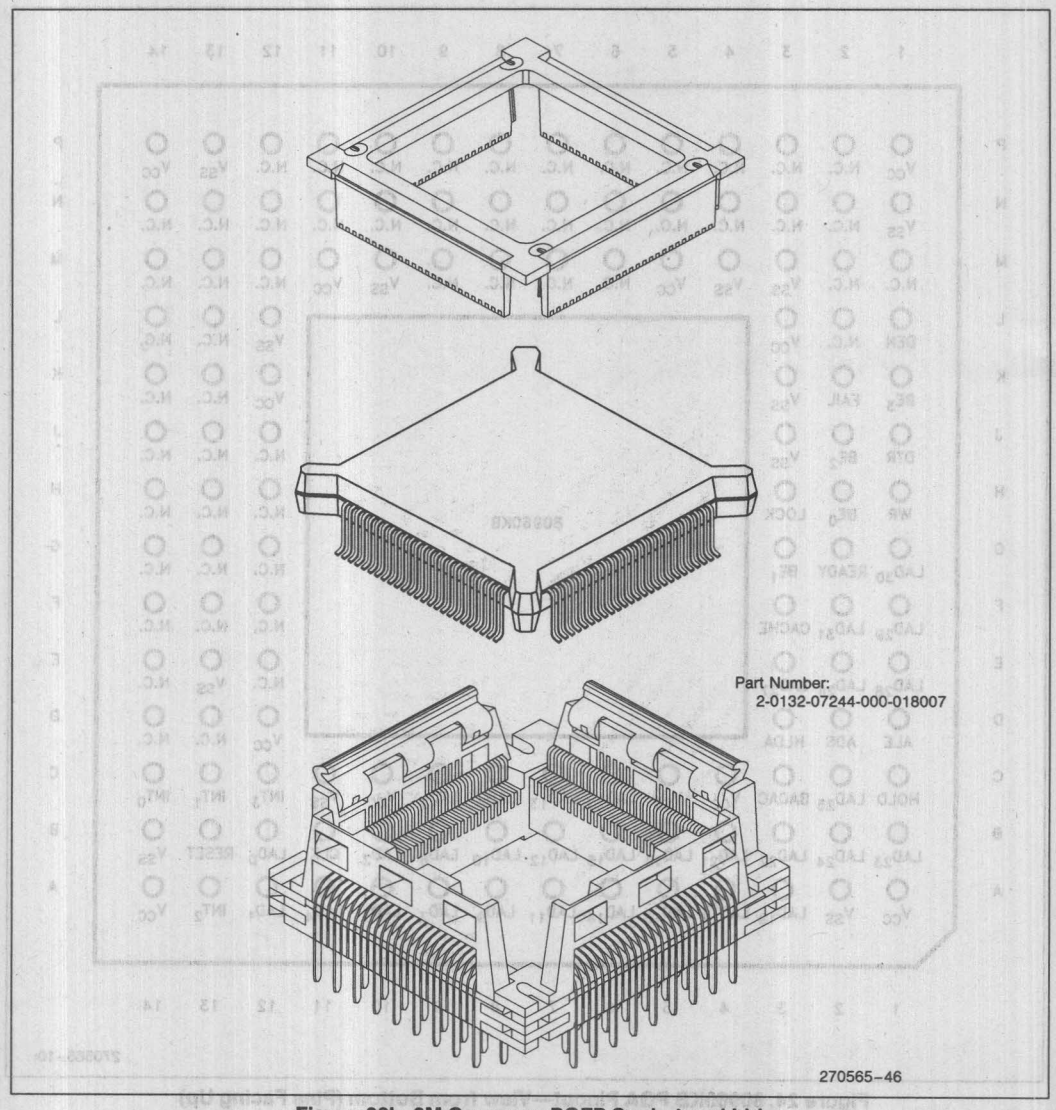


Figure 23b. 3M Company PQFP Socket and Lid

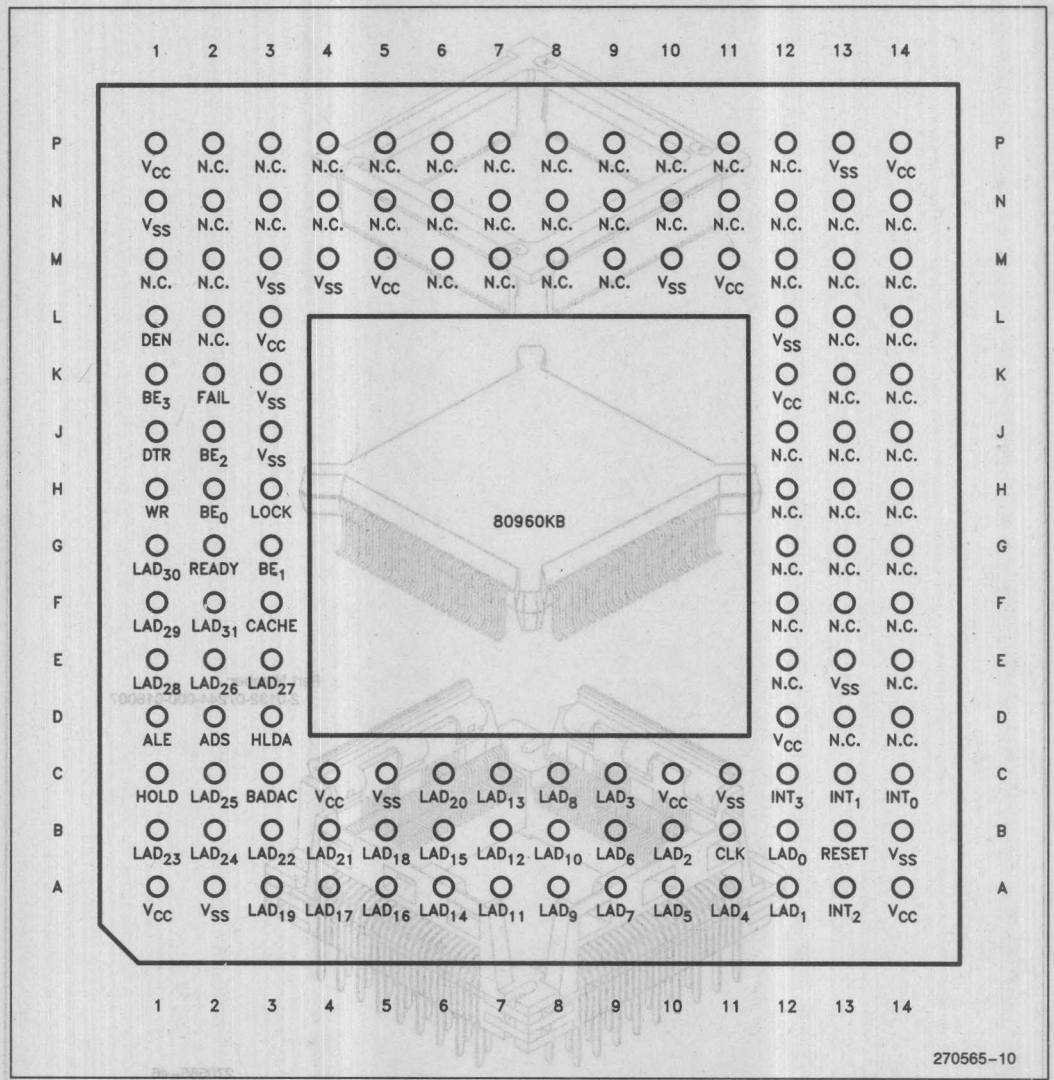


Figure 24. 80960KB PGA Pinout—View from Bottom (Pins Facing Up)

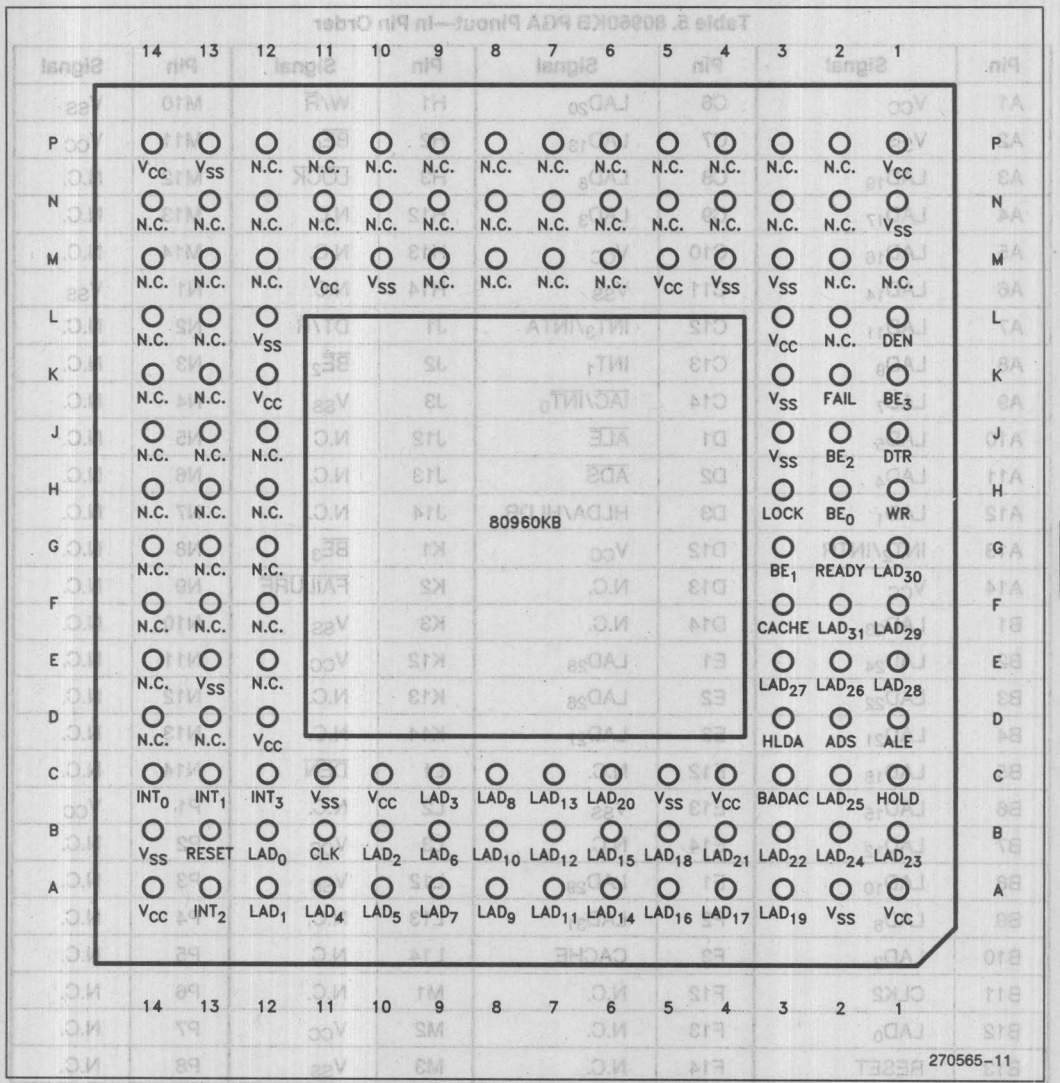


Figure 25. 80960KB PGA Pinout—View from Top (Pins Facing Down)

Table 5. 80960KB PGA Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
A1	V_{CC}	C6	LAD_{20}	H1	W/$\overline{R}$	M10	V_{SS}
A2	V_{SS}	C7	LAD_{13}	H2	$\overline{BE_0}$	M11	V_{CC}
A3	LAD_{19}	C8	LAD_8	H3	$\overline{LOCK}$	M12	N.C.
A4	LAD_{17}	C9	LAD_3	H12	N.C	M13	N.C.
A5	LAD_{16}	C10	V_{CC}	H13	N.C.	M14	N.C.
A6	LAD_{14}	C11	V_{SS}	H14	N.C.	N1	V_{SS}
A7	LAD_{11}	C12	$\overline{INT_3}$/$\overline{INTA}$	J1	DT/$\overline{R}$	N2	N.C.
A8	LAD_9	C13	INT_1	J2	$\overline{BE_2}$	N3	N.C.
A9	LAD_7	C14	$\overline{IAC}$/$\overline{INT_0}$	J3	V_{SS}	N4	N.C.
A10	LAD_5	D1	$\overline{ALE}$	J12	N.C	N5	N.C.
A11	LAD_4	D2	$\overline{ADS}$	J13	N.C.	N6	N.C.
A12	LAD_1	D3	HLDA/HLDR	J14	N.C.	N7	N.C.
A13	INT_2/INTR	D12	V_{CC}	K1	$\overline{BE_3}$	N8	N.C.
A14	V_{CC}	D13	N.C.	K2	$\overline{FAILURE}$	N9	N.C.
B1	LAD_{23}	D14	N.C.	K3	V_{SS}	N10	N.C.
B2	LAD_{24}	E1	LAD_{28}	K12	V_{CC}	N11	N.C.
B3	LAD_{22}	E2	LAD_{26}	K13	N.C.	N12	N.C.
B4	LAD_{21}	E3	LAD_{27}	K14	N.C.	N13	N.C.
B5	LAD_{18}	E12	N.C.	L1	$\overline{DEN}$	N14	N.C.
B6	LAD_{15}	E13	V_{SS}	L2	N.C.	P1	V_{CC}
B7	LAD_{12}	E14	N.C.	L3	V_{CC}	P2	N.C.
B8	LAD_{10}	F1	LAD_{29}	L12	V_{SS}	P3	N.C.
B9	LAD_6	F2	LAD_{31}	L13	N.C.	P4	N.C.
B10	LAD_2	F3	CACHE	L14	N.C.	P5	N.C.
B11	CLK2	F12	N.C.	M1	N.C.	P6	N.C.
B12	LAD_0	F13	N.C.	M2	V_{CC}	P7	N.C.
B13	RESET	F14	N.C.	M3	V_{SS}	P8	N.C.
B14	V_{SS}	G1	LAD_{30}	M4	V_{SS}	P9	N.C.
C1	HOLD/HLDAR	G2	$\overline{READY}$	M5	V_{CC}	P10	N.C.
C2	LAD_{25}	G3	$\overline{BE_1}$	M6	N.C.	P11	N.C.
C3	$\overline{BADAC}$	G12	N.C.	M7	N.C.	P12	N.C.
C4	V_{CC}	G13	N.C.	M8	N.C.	P13	V_{SS}
C5	V_{SS}	G14	N.C.	M9	N.C.	P14	V_{CC}

Table 6. 80960KB PGA Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	D2	LAD_{15}	B6	N.C.	J14	N.C.	P9
$\overline{ALE}$	D1	LAD_{16}	A5	N.C.	K13	N.C.	P10
$\overline{BADAC}$	C3	LAD_{17}	A4	N.C.	K14	N.C.	P11
$\overline{BE_0}$	H2	LAD_{18}	B5	N.C.	L13	N.C.	P12
$\overline{BE_1}$	G3	LAD_{19}	A3	N.C.	L14	N.C.	L2
$\overline{BE_2}$	J2	LAD_{20}	C6	N.C.	M1	$\overline{READY}$	G2
$\overline{BE_3}$	K1	LAD_{21}	B4	N.C.	M6	RESET	B13
CACHE	F3	LAD_{22}	B3	N.C.	M7	V_{CC}	A1
CLK2	B11	LAD_{23}	B1	N.C.	M8	V_{CC}	A14
$\overline{DEN}$	L1	LAD_{24}	B2	N.C.	M9	V_{CC}	C4
DT/$\overline{R}$	J1	LAD_{25}	C2	N.C.	M12	V_{CC}	C10
$\overline{FAILURE}$	K2	LAD_{26}	E2	N.C.	M13	V_{CC}	D12
HLDA/HOLDR	D3	LAD_{27}	E3	N.C.	M14	V_{CC}	K12
HOLD/HLDAR	C1	LAD_{28}	E1	N.C.	N2	V_{CC}	L3
$\overline{IAC}/\overline{INT_0}$	C14	LAD_{29}	F1	N.C.	N3	V_{CC}	M2
INT_1	C13	LAD_{30}	G1	N.C.	N4	V_{CC}	M5
INT_2/INTR	A13	LAD_{31}	F2	N.C.	N5	V_{CC}	M11
$\overline{INT_3}/\overline{INTA}$	C12	$\overline{LOCK}$	H3	N.C.	N6	V_{CC}	P1
LAD_0	B12	N.C.	D13	N.C.	N7	V_{CC}	P14
LAD_1	A12	N.C.	D14	N.C.	N8	V_{SS}	A2
LAD_2	B10	N.C.	E12	N.C.	N9	V_{SS}	B14
LAD_3	C9	N.C.	E14	N.C.	N10	V_{SS}	C5
LAD_4	A11	N.C.	F12	N.C.	N11	V_{SS}	C11
LAD_5	A10	N.C.	F13	N.C.	N12	V_{SS}	E13
LAD_6	B9	N.C.	F14	N.C.	N13	V_{SS}	J3
LAD_7	A9	N.C.	G12	N.C.	N14	V_{SS}	K3
LAD_8	C8	N.C.	G13	N.C.	P2	V_{SS}	L12
LAD_9	A8	N.C.	G14	N.C.	P3	V_{SS}	M3
LAD_{10}	B8	N.C.	H12	N.C.	P4	V_{SS}	M4
LAD_{11}	A7	N.C.	H13	N.C.	P5	V_{SS}	M10
LAD_{12}	B7	N.C.	H14	N.C.	P6	V_{SS}	N1
LAD_{13}	C7	N.C.	J12	N.C.	P7	V_{SS}	P13
LAD_{14}	A6	N.C.	J13	N.C.	P8	W/$\overline{R}$	H1

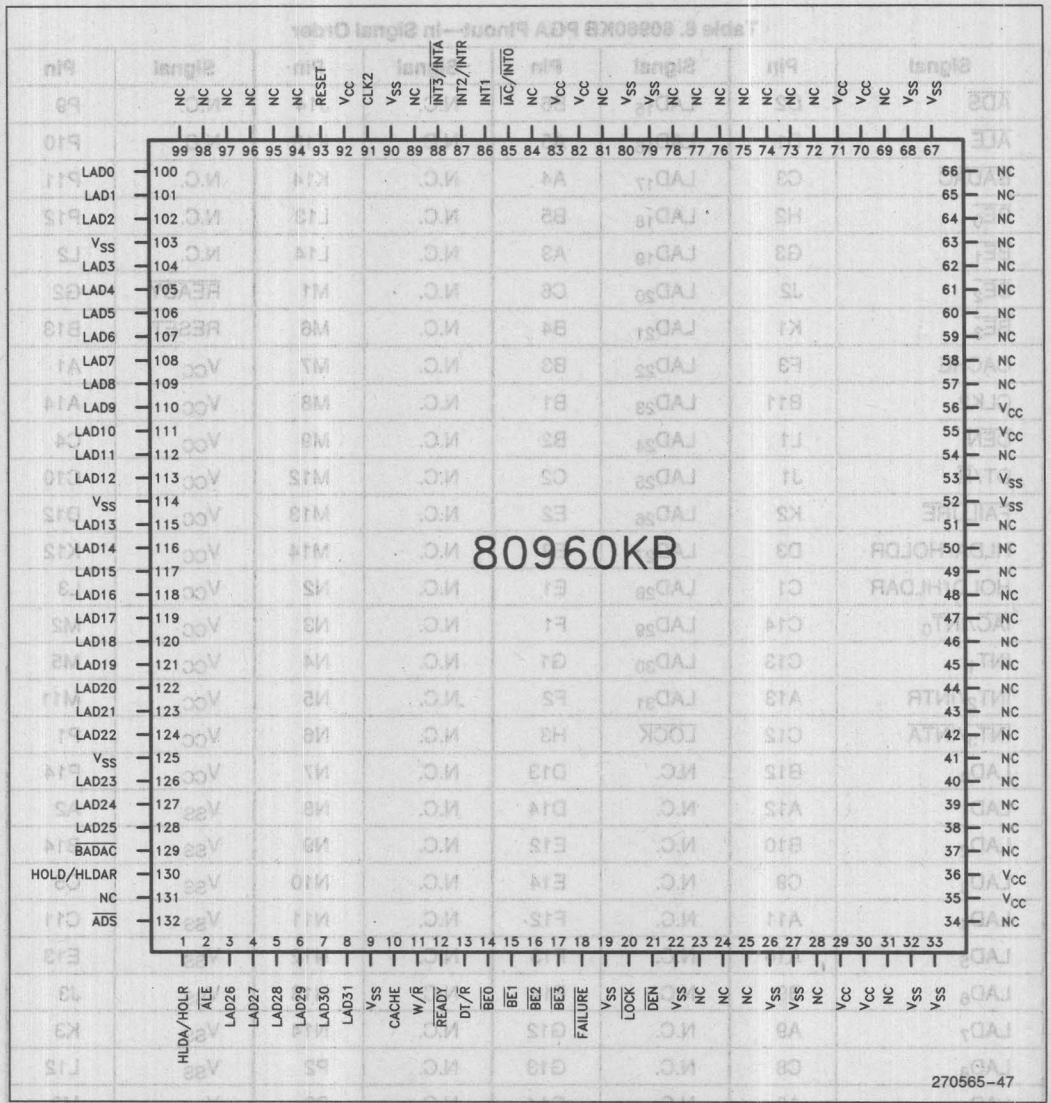


Figure 32. 80960KB PQFP Pinout—View from Top

Table 8. 80960KB Plastic Package Pinout - In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
1	HLDA/HOLR	34	N.C.	67	V_{SS}	100	LAD0
2	$\overline{ALE}$	35	V_{CC}	68	V_{SS}	101	LAD1
3	LAD26	36	V_{CC}	69	N.C.	102	LAD2
4	LAD27	37	N.C.	70	V_{CC}	103	V_{SS}
5	LAD28	38	N.C.	71	V_{CC}	104	LAD3
6	LAD29	39	N.C.	72	N.C.	105	LAD4
7	LAD30	40	N.C.	73	N.C.	106	LAD5
8	LAD31	41	N.C.	74	N.C.	107	LAD6
9	V_{SS}	42	N.C.	75	N.C.	108	LAD7
10	CACHE	43	N.C.	76	N.C.	109	LAD8
11	W/$\overline{R}$	44	N.C.	77	N.C.	110	LAD9
12	$\overline{READY}$	45	N.C.	78	N.C.	111	LAD10
13	DT/$\overline{R}$	46	N.C.	79	V_{SS}	112	LAD11
14	$\overline{BE0}$	47	N.C.	80	V_{SS}	113	LAD12
15	$\overline{BE1}$	48	N.C.	81	N.C.	114	V_{SS}
16	$\overline{BE2}$	49	N.C.	82	V_{CC}	115	LAD13
17	$\overline{BE3}$	50	N.C.	83	V_{CC}	116	LAD14
18	$\overline{FAILURE}$	51	N.C.	84	N.C.	117	LAD15
19	V_{SS}	52	V_{SS}	85	$\overline{IAC}/\overline{INT0}$	118	LAD16
20	$\overline{LOCK}$	53	V_{SS}	86	INT1	119	LAD17
21	$\overline{DEN}$	54	N.C.	87	INT2/INTR	120	LAD18
22	V_{SS}	55	V_{CC}	88	$\overline{INT3}/\overline{INTA}$	121	LAD19
23	N.C.	56	V_{CC}	89	N.C.	122	LAD20
24	N.C.	57	N.C.	90	V_{SS}	123	LAD21
25	N.C.	58	N.C.	91	CLK2	124	LAD22
26	V_{SS}	59	N.C.	92	V_{CC}	125	V_{SS}
27	V_{SS}	60	N.C.	93	RESET	126	LAD23
28	N.C.	61	N.C.	94	N.C.	127	LAD24
29	V_{CC}	62	N.C.	95	N.C.	128	LAD25
30	V_{CC}	63	N.C.	96	N.C.	129	$\overline{BADAC}$
31	N.C.	64	N.C.	97	N.C.	130	HOLD/HLDAR
32	V_{SS}	65	N.C.	98	N.C.	131	N.C.
33	V_{SS}	66	N.C.	99	N.C.	132	$\overline{ADS}$

Table 9. 80960KB Plastic Package Pinout - In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	132	LAD22	124	N.C.	46	N.C.	98
$\overline{ALE}$	2	LAD23	126	N.C.	47	N.C.	99
$\overline{BADAC}$	129	LAD24	127	N.C.	48	N.C.	131
$\overline{BE0}$	14	LAD25	128	N.C.	49	$\overline{READY}$	12
$\overline{BE1}$	15	LAD26	3	N.C.	50	RESET	93
$\overline{BE2}$	16	LAD27	4	N.C.	51	V_{CC}	29
$\overline{BE3}$	17	LAD28	5	N.C.	54	V_{CC}	30
CACHE	10	LAD29	6	N.C.	57	V_{CC}	35
CLK2	91	LAD3	104	N.C.	58	V_{CC}	36
$\overline{DEN}$	21	LAD30	7	N.C.	59	V_{CC}	55
DT/$\overline{R}$	13	LAD31	8	N.C.	60	V_{CC}	70
$\overline{FAILURE}$	18	LAD4	105	N.C.	61	V_{CC}	71
HLDA/HOLR	1	LAD5	106	N.C.	62	V_{CC}	82
HOLD/HLDAR	130	LAD6	107	N.C.	63	V_{CC}	83
$\overline{IAC}$/$\overline{INT0}$	85	LAD7	108	N.C.	64	V_{CC}	92
INT1	86	LAD8	109	N.C.	65	V_{SS}	9
INT2/INTR	87	LAD9	110	N.C.	66	V_{SS}	19
$\overline{INT3}$/$\overline{INTA}$	88	$\overline{LOCK}$	20	N.C.	69	V_{SS}	22
LAD0	100	N.C.	23	N.C.	72	V_{SS}	26
LAD1	101	N.C.	24	N.C.	73	V_{SS}	27
LAD10	111	N.C.	25	N.C.	74	V_{SS}	32
LAD11	112	N.C.	28	N.C.	75	V_{SS}	33
LAD12	113	N.C.	31	N.C.	76	V_{SS}	52
LAD13	115	N.C.	34	N.C.	77	V_{SS}	53
LAD14	116	N.C.	37	N.C.	78	V_{SS}	67
LAD15	117	N.C.	38	N.C.	81	V_{SS}	68
LAD16	118	N.C.	39	N.C.	84	V_{SS}	79
LAD17	119	N.C.	40	N.C.	89	V_{SS}	80
LAD18	120	N.C.	41	N.C.	94	V_{SS}	90
LAD19	121	N.C.	42	N.C.	94	V_{SS}	103
LAD2	102	N.C.	43	N.C.	95	V_{SS}	114
LAD20	122	N.C.	44	N.C.	96	V_{SS}	125
LAD21	123	N.C.	45	N.C.	97	W/$\overline{R}$	11

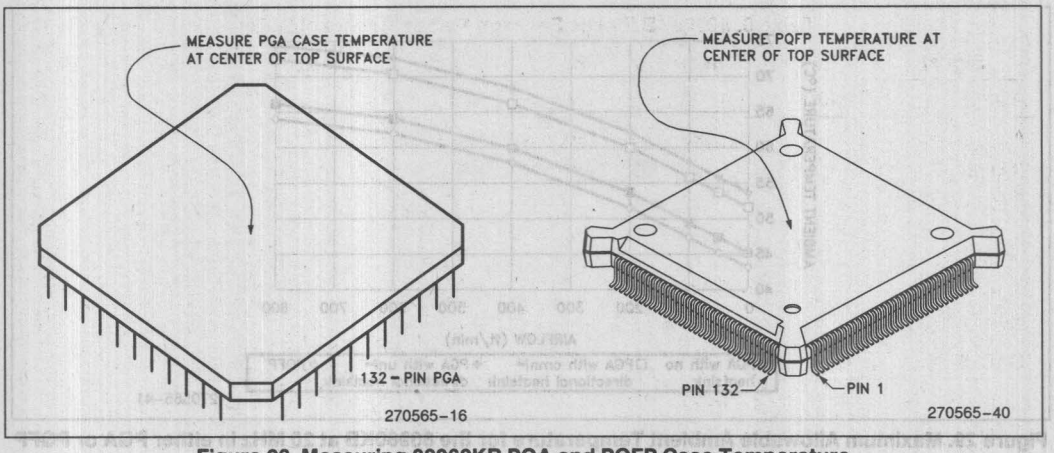


Figure 26. Measuring 80960KB PGA and PQFP Case Temperature

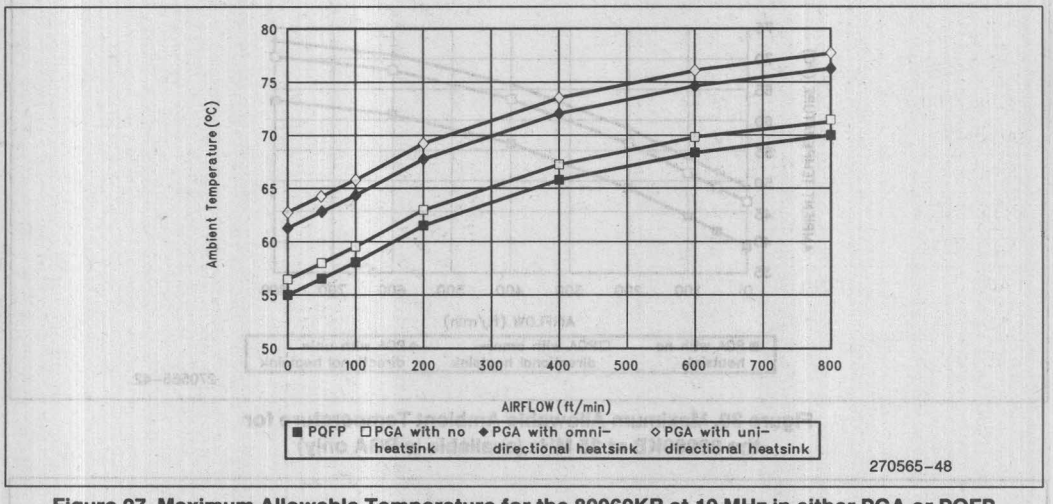


Figure 27. Maximum Allowable Temperature for the 80960KB at 10 MHz in either PGA or PQFP

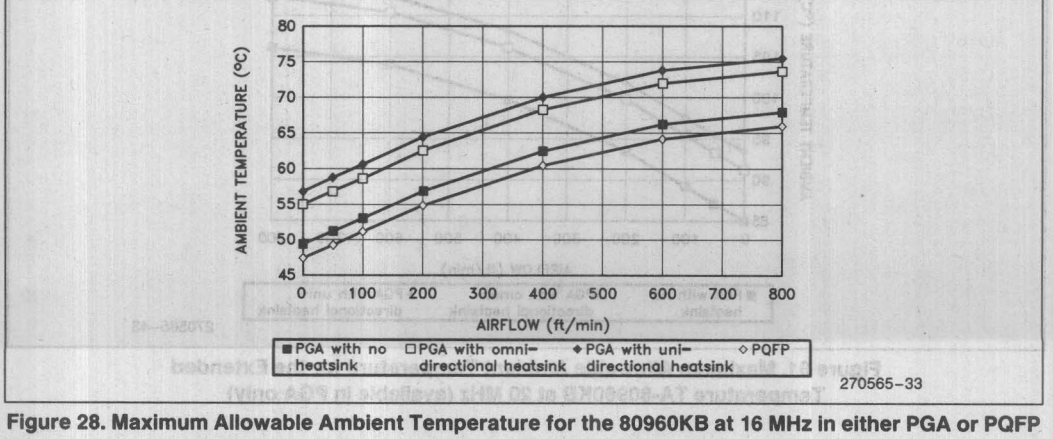


Figure 28. Maximum Allowable Ambient Temperature for the 80960KB at 16 MHz in either PGA or PQFP

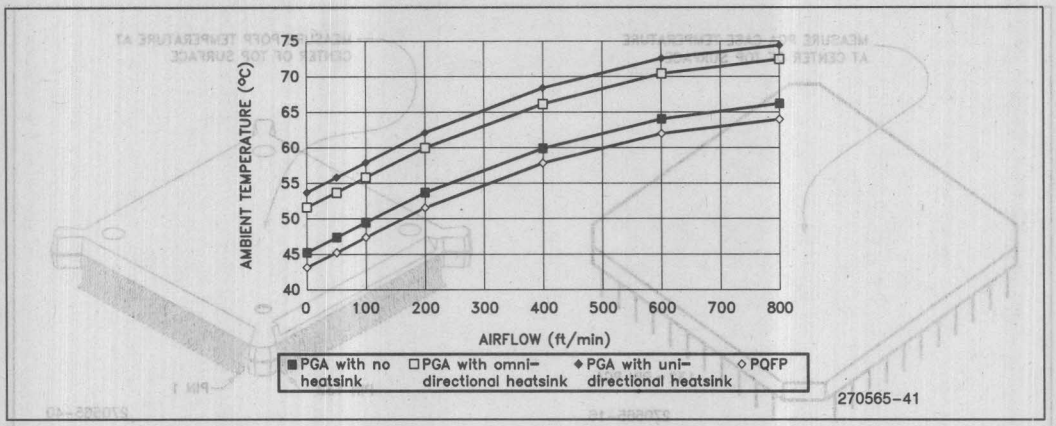


Figure 29. Maximum Allowable Ambient Temperature for the 80960KB at 20 MHz in either PGA or PQFP

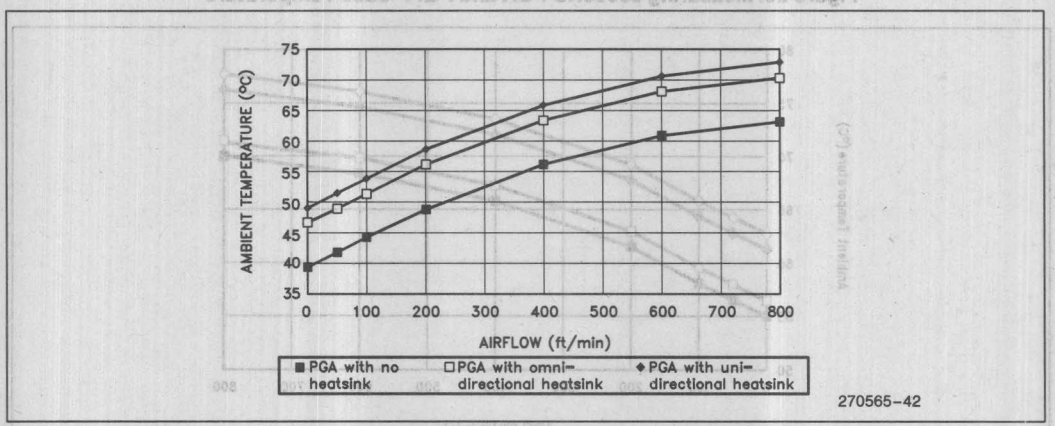


Figure 30. Maximum Allowable Ambient Temperature for the 80960KB at 25 MHz (available in PGA only)

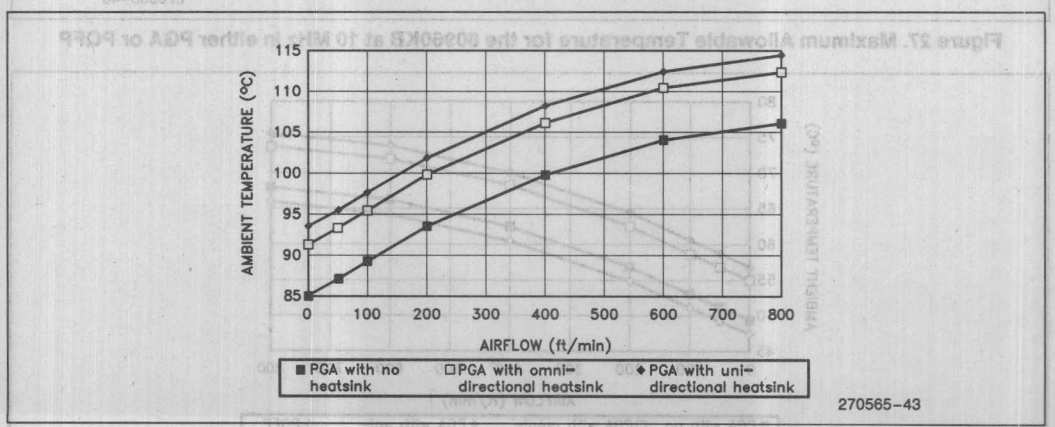
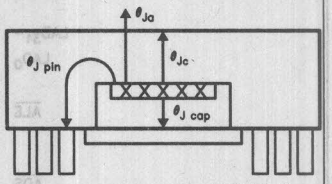


Figure 31. Maximum Allowable Ambient Temperature for the Extended Temperature TA-80960KB at 20 MHz (available in PGA only)

Table 10. 80960KB PGA Package Thermal Characteristics

Thermal Resistance—°C/Watt							
Parameter	Airflow—ft./min (m/sec)						
	0 (0)	50 (0.25)	100 (0.50)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)
θ Junction-to-Case (Case Measured as shown in Figure 26)	2	2	2	2	2	2	2
θ Case-to-Ambient (No Heatsink)	19	18	17	15	12	10	9
θ Case-to-Ambient (with Omnidirectional Heatsink)	16	15	14	12	9	7	6
θ Case-to-Ambient (with Unidirectional) Heatsink)	15	14	13	11	8	6	5



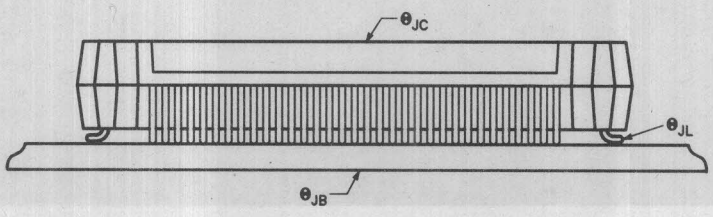
270565-45

NOTES:
1. This table applies to 80960KB PGA plugged into socket or soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. $\theta_{J\text{-}CAP}$ = 4°C/w (approx.)
   $\theta_{J\text{-}PIN}$ = 4°C/w (inner pins) (approx.)
   $\theta_{J\text{-}PIN}$ = 8°C/w (outer pins) (approx.)

Table 11. 80960KB PQFP Package Thermal Characteristics

PQFP Thermal Resistance—°C/Watt							
Parameter	Airflow—ft./min (m/sec)						
	0 (0)	50 (0.25)	100 (0.50)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)
θ Junction-to-Case (Case Measured as shown in Figure 26)	6	6	6	6	6	6	6
θ Case-to-Ambient (No Heatsink)	20	19	18	16	13	11	10

NOTES:
1. This table applies to 80960KB PQFP soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. θ_{JL} = 18°C/Watt
   θ_{JB} = 18°C/Watt



270565-44

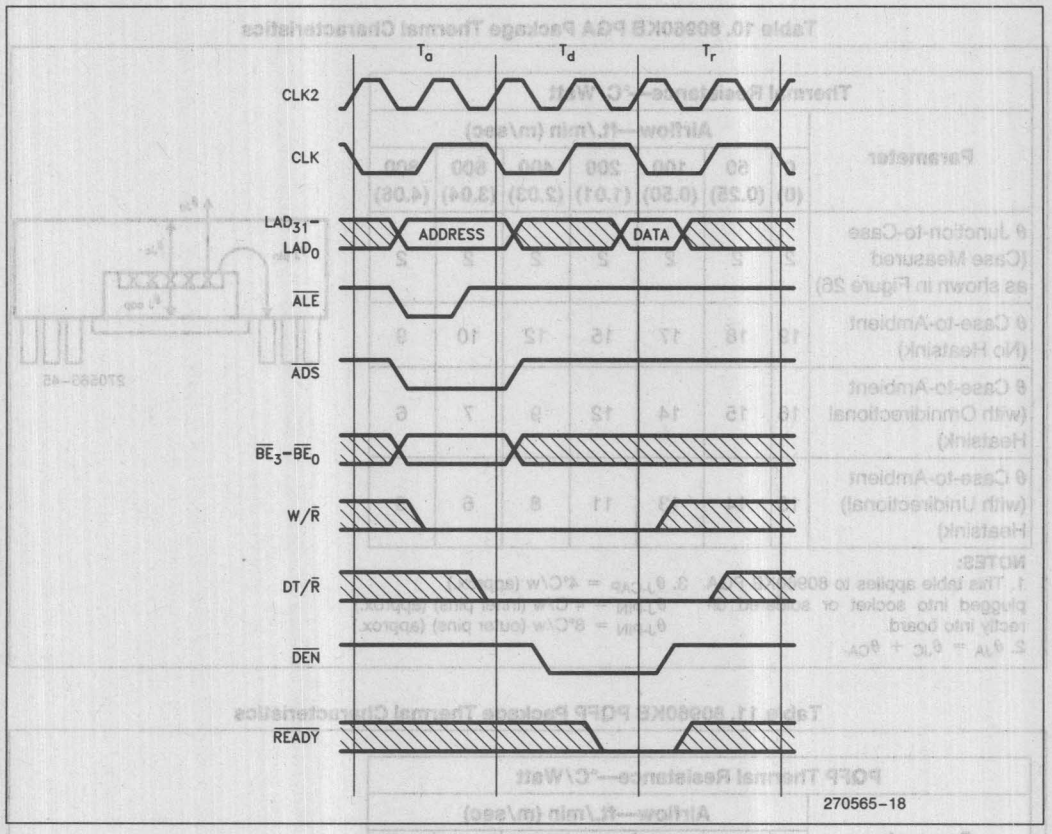


Figure 32. Read Transaction

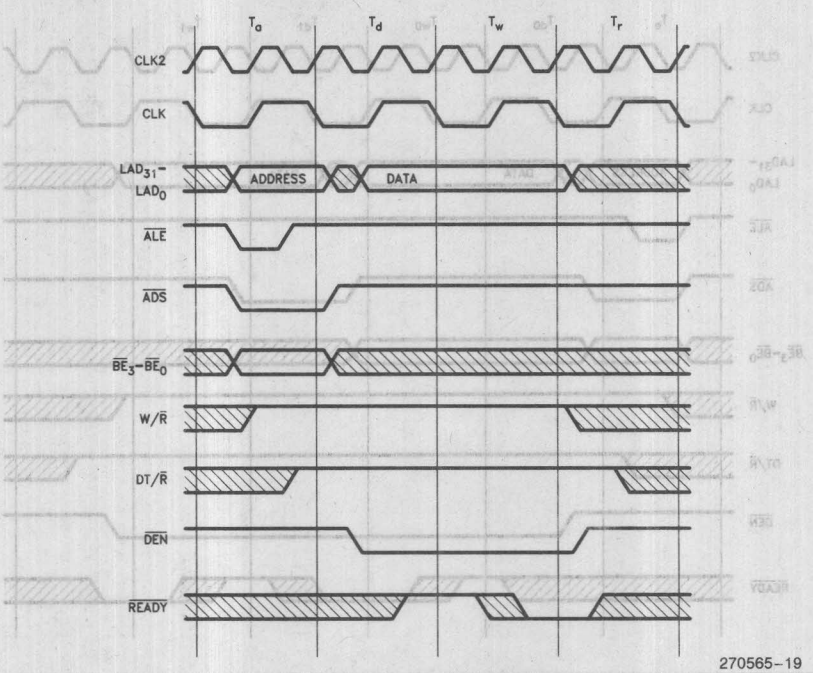


Figure 33. Write Transaction with One Wait State

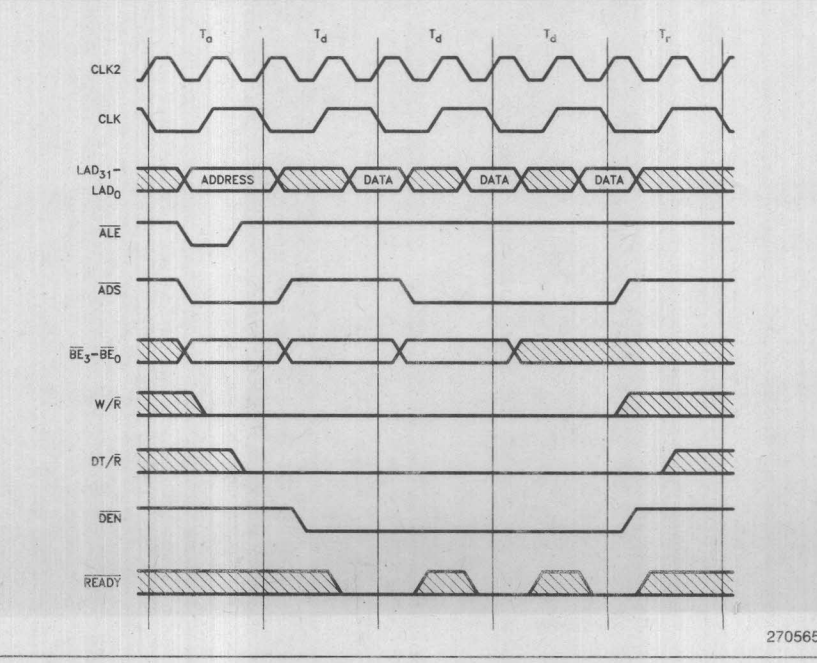


Figure 34. Burst Read Transaction

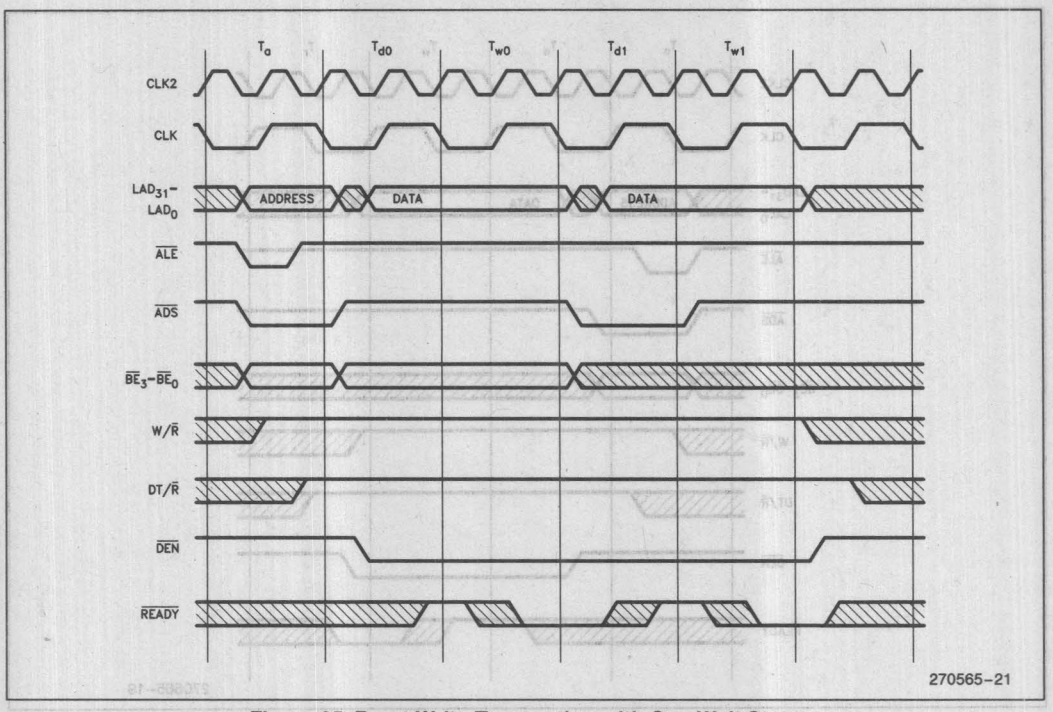
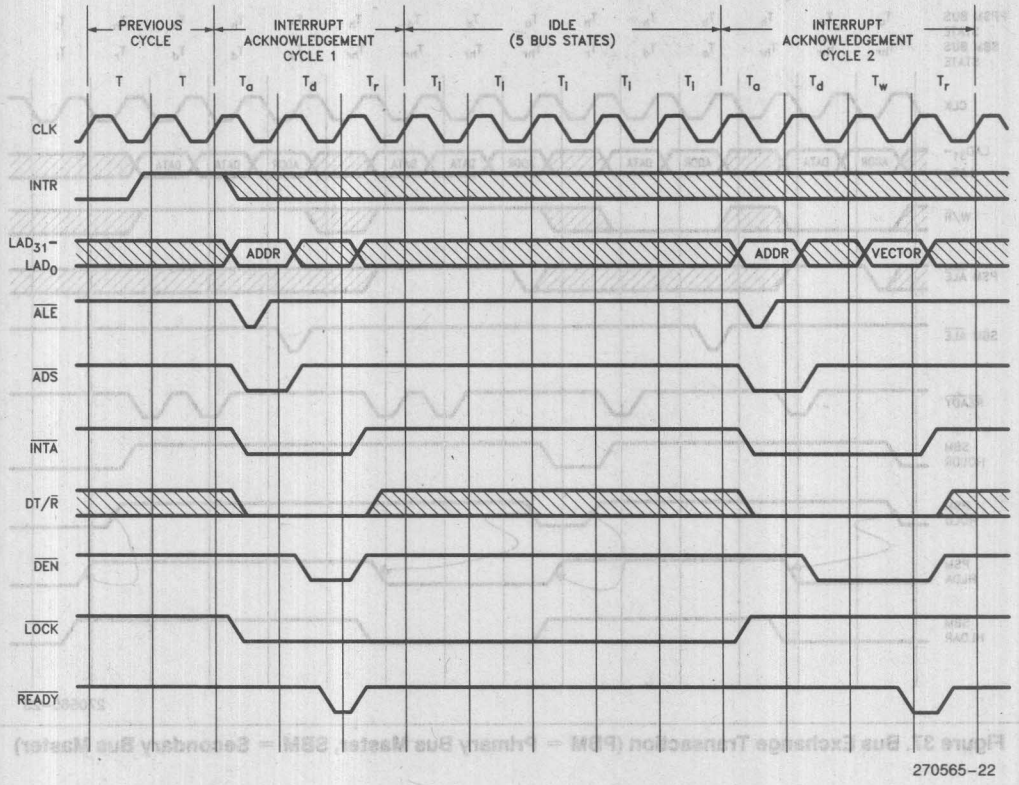


Figure 35. Burst Write Transaction with One Wait State



NOTE:
INTR can go low no sooner than 5 ns (input hold time) following the beginning of interrupt acknowledgement cycle 1. For a second interrupt to be acknowledged, INTR must be low for at least three cycles before it can be reasserted.

Figure 36. Interrupt Acknowledge Transaction

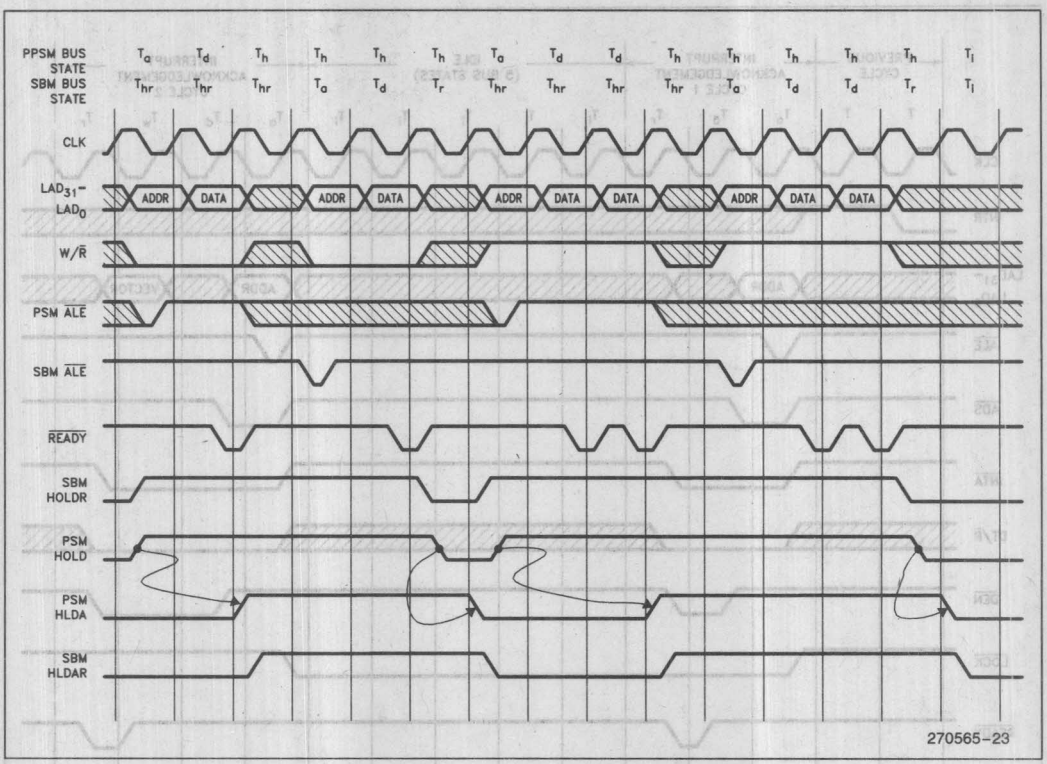


Figure 37. Bus Exchange Transaction (PBM = Primary Bus Master, SBM = Secondary Bus Master)

80960CA Product Overview and Data Sheets

4

4 80960CA Product Overview and Data Sheets

October 1989

80960CA Product Overview

32-Bit High-Performance Embedded Processor with On-Chip DMA Controller, Interrupt Controller, High-Speed Bus Unit, Instruction and Register Caches

Order Number: 270669-001

80960CA PRODUCT OVERVIEW

CONTENTS

PAGE

1.0 PURPOSE 4-3

2.0 80960CA 32-BIT EMBEDDED PROCESSOR 4-3

2.1 80960 Architecture 4-3

2.2 80960 C-Series Core 4-4

2.3 80960CA System Peripherals 4-4

3.0 EXECUTION ENVIRONMENT 4-4

3.1 Registers and Literals 4-4

3.2 Address Space and Memory 4-6

3.3 Memory Addressing Modes 4-7

3.4 Data Types 4-8

3.5 Instruction Set 4-9

3.6 Arithmetic Controls 4-14

3.7 Process Management 4-14

3.8 Call and Return Mechanism 4-15

3.9 Interrupts 4-19

3.10 Fault Handling and Instruction Tracing 4-21

4.0 80960CA SYSTEM IMPLEMENTATION 4-25

4.1 Peripheral Interface 4-25

4.2 Bus Controller Unit 4-25

4.3 DMA Controller 4-30

4.4 Interrupt Controller 4-34

APPENDIX A 80960CA CORE IMPLEMENTATION ... 4-36

A.1 Instruction Sequencer 4-36

A.2 Register File 4-38

A.3 Execution Unit 4-38

A.4 Multiply Divide Unit 4-38

A.5 Address Generation Unit 4-38

A.6 Data RAM and Local Register Cache 4-38

80960CA PRODUCT OVERVIEW

1.0 PURPOSE

The *80960CA Product Overview* is a summary of the features and operation of Intel's 80960CA Embedded Processor. The Product Overview is intended for those who are not familiar with the 80960 architecture or the 80960CA, a product built around this architecture. The 80960CA Product Overview provides a programmer or a system designer with a quick, global view of software and hardware design considerations for the 80960CA. For further information, refer to the following reference documents:

— The *80960CA User's Manual* contains detailed technical information and examples for designing embedded systems using the 80960CA.

— The *80960CA Data Sheet* provides electrical specifications for the device, such as the DC and AC parameters, operating conditions, and packaging specifications.

2.0 80960CA 32-BIT EMBEDDED PROCESSOR

The 80960CA (Figure 2-1) is optimized for embedded processing applications. This product features the high-performance C-Series core plus built-in system peripherals, effectively integrating a high-speed CPU and system components onto a single silicon die. The 80960CA is a member of Intel's 80960 embedded processor family. Each member of the 80960 family is based on a common architectural definition referred to as the *core architecture*.

An 80960 family member, such as the 80960CA, is made up of an implementation of the core architecture plus application-specific extensions. These extensions may consist of integrated peripherals, instruction-set extensions, or additional registers and caches beyond those defined by the architecture. The common core architecture provides a basis for code compatibility for all 80960 family products, while application-specific extensions optimize a particular product for a class of applications.

The 80960 architectural target is the execution of multiple instructions per clock (i.e., fractional clocks per instruction). By defining an architecture which supports parallel instruction execution and out-of-order instruction execution, performance advances are not constrained by the system clock.

The 80960CA is capable of launching and executing instructions in parallel. This is accomplished by the use of advanced silicon technology as well as innovative "microarchitectural" constructs. The term microarchitecture refers to the implementation of the instruction set and programming resources. For example, different microarchitectures may have different pipeline construction, internal bus widths, register set porting, degrees of parallelism, and cache parameterization (two-way, four-way, etc.).

A principal objective of the 80960 architecture is to provide the framework to allow microarchitectural advances to translate directly into increased performance without architectural limitations.

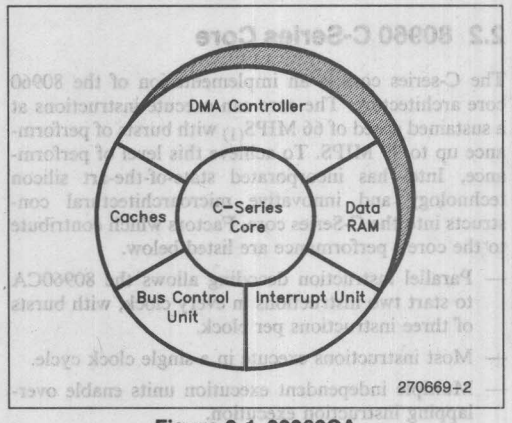


Figure 2-1. 80960CA

2.1 80960 Architecture

Embedded applications are cost sensitive, require a different mix of instructions than reprogrammable applications, have demanding interrupt response requirements, and often use real-time executives rather than full-blown operating systems. The 80960 architecture was developed with these factors in mind. Several key optimizations which are provided by the architecture are explained below.

Instruction Set: Powerful Boolean operations are provided. Frequently executed functions are available as single instructions for greater code density and performance. Call, Return, Compare-and-Branch, Conditional-Compare, Compare-and-Increment or Decrement, and Bit-Field-Extract are each single instructions.

Interrupts: A priority interrupt structure simplifies the management of real-time events. With 31 discrete levels of priority and 248 possible interrupt-handling procedures, this structure provides the low latency and high throughput interrupt handling required in embedded processor applications.

Faults: A generalized fault-handling mechanism simplifies the task of detecting errant arithmetic calculations or other conditions that typically require a significant amount of in-line user code.

Application-Specific Extensions: The core architecture is designed to accept application-specific extensions such as instruction set extensions (e.g., string functions, floating point), special purpose registers, larger caches, on-chip program and data memory, a memory management and protection unit, fault-tolerance support, multiprocessing support, and real-time peripherals (DMA, serial ports, etc.).

2.2 80960 C-Series Core

The C-series core is an implementation of the 80960 core architecture. The core can execute instructions at a sustained speed of 66 MIPS(1) with bursts of performance up to 99 MIPS. To achieve this level of performance, Intel has incorporated state-of-the-art silicon technology and innovative microarchitectural constructs into the C-Series core. Factors which contribute to the core's performance are listed below.

- Parallel instruction decoding allows the 80960CA to start two instructions in every clock, with bursts of three instructions per clock.
- Most instructions execute in a single clock cycle.
- Multiple independent execution units enable overlapping instruction execution.
- Advanced silicon technology allows operation with a 33 MHz internal clock.
- Efficient instruction pipeline is designed to minimize pipeline break losses.
- Register and resource scoreboarding transparently manage parallel execution.
- Branch look-ahead feature enables branches to execute in parallel with other instructions.
- Local register cache is integrated on-chip.
- 1 Kbyte two-way set associative instruction cache is integrated on-chip.
- 1 Kbyte Static Data RAM is integrated on-chip.

These factors combine to make the 80960CA an ultra-high performance computing engine.

NOTE:
1. Single clock instructions at 33 MHz.

2.3 80960CA System Peripherals

The 80960CA features several extensions to the core architecture in the form of integrated peripherals. These peripherals are intended to reduce the external system requirements needed for embedded applications. These peripherals are described below.

Bus Controller Unit: A 32-bit high-performance bus controller interfaces the 80960CA to external memory and peripherals. The bus controller transfers instructions or data at a maximum rate of 132 Mbytes per second.(2) Internally programmable wait states and 16 separately configurable memory regions allow the bus controller to interface with a variety of memory subsystems with minimum system complexity and maximum performance.

DMA Controller: A four channel DMA controller performs high speed data transfers between peripherals and memory. The DMA controller provides advanced features such as data chaining, byte assembly and disassembly, and a fly-by mode capable of transfer speeds of up to 66 Mbytes per second. The DMA controller features a performance and flexibility which is only possible by integrating the DMA controller and the 80960CA core.

Interrupt Controller: A priority interrupt controller manages 8 external interrupt inputs, 4 internal interrupt sources from the DMA controller, and a single non-maskable interrupt input (NMI). A total of 248 external interrupt sources are supported by the interrupt controller by configuring the 8 external interrupt pins as an 8-bit input port. The interrupt controller provides the mechanism for the low latency and high throughput interrupt service featured by the 80960CA. The interrupt latency for the 80960CA is typically less than 1 μs.

3.0 EXECUTION ENVIRONMENT

The *Execution Environment* (Figure 3-1) refers to the resources which are available for executing code on the 80960CA. The following sections describe the elements of the execution environment.

3.1 Registers and Literals

The 80960CA provides four types of working data registers: *Global Registers, Local Registers, Special Function Registers* (SFRs), and *Control Registers.*

Global and local registers are general purpose 32-bit data registers. The SFRs and the control registers provide a programmer's interface to the on-chip peripherals (i.e., the DMA controller, interrupt controller, and bus controller).

NOTE:
2. 33 MHz internal clock, load or instruction fetch on 0 wait state, pipelined burst bus.

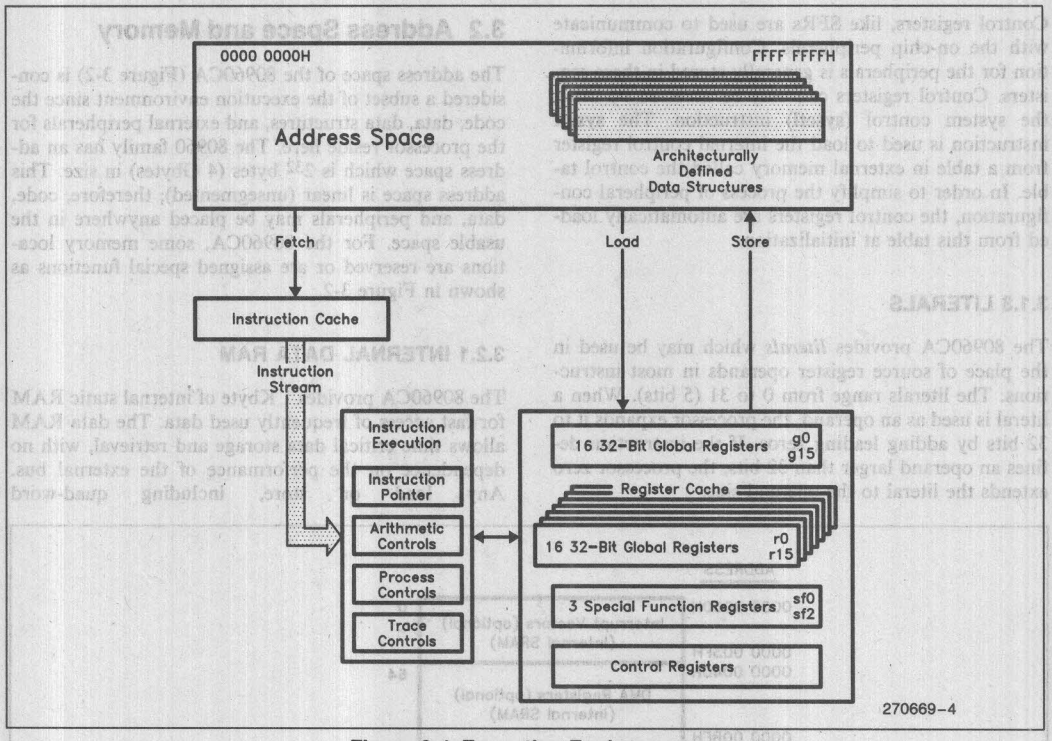


Figure 3-1. Execution Environment

The 80960 architecture is a register-oriented architecture. That is, operands and results of instructions are placed in working data registers rather than in memory. Since the architecture is register oriented, an ample supply of registers is provided. The architecture's working register set consists of 16, 32-bit global registers and 16, 32-bit local registers.

3.1.1 GLOBAL AND LOCAL REGISTERS

The procedure call and return mechanism, which is part of the 80960 architecture, inspires the names given to the local and global registers. When a procedure call or return is executed, the contents of global registers are preserved across procedure boundaries. In other words, the same set of global registers is used for each procedure. A new set of local registers, however, is allocated for each procedure. The 80960's call and return mechanism is explained in Section 3.8.

The 80960CA supplies 16, 32-bit global registers designated **g0** through **g15**. Registers **g0** through **g14** are general purpose global registers. Register **g15** is reserved for the current Frame Pointer. This register is available in assembly language as the **fp** register. The **fp** contains the address of the first byte in the current stack frame. The **fp** register and the stack frame are described in Section 3.8.

The 80960CA supplies 16, 32-bit **Local Registers** designated **r0** through **r15**. Registers **r3** through **r15** are general purpose local registers. Registers **r0**, **r1**, and **r2** are reserved for special functions as follows: **r0** contains the Previous Frame Pointer, **r1** contains the Stack Pointer, and **r2** is reserved for the Return Instruction Pointer. These registers are available in assembly language as, respectively, the **pfp**, **sp**, and **rip** registers. The **pfp**, **sp**, and **rip** registers manage stack frame linkage for the 80960's procedure call and return mechanism. The function of these registers is decribed in Section 3.8.

3.1.2 SPECIAL FUNCTION REGISTERS AND CONTROL REGISTERS

The 80960CA uses 3 Special Function Registers (SFRs) for communicating with on-chip peripherals. These SFR's are an architectural extension specific to the 80960CA. The SFRs on the 80960CA are designated as **sf0**, **sf1**, and **sf2**. SFRs are accessed as source operands by most of the 80960CA's instructions. The registers serve as part of the programmer's interface to the DMA and interrupt controller.

Control registers, like SFRs are used to communicate with the on-chip peripherals. Configuration information for the peripherals is generally stored in these registers. Control registers can only be accessed by using the system control (**sysctl**) instruction. The **sysctl** instruction is used to load the internal control register from a table in external memory called the control table. In order to simplify the process of peripheral configuration, the control registers are automatically loaded from this table at initialization.

3.1.3 LITERALS

The 80960CA provides *literals* which may be used in the place of source register operands in most instructions. The literals range from 0 to 31 (5 bits). When a literal is used as an operand, the processor expands it to 32 bits by adding leading zeros. If the instruction defines an operand larger than 32 bits, the processor zero extends the literal to the operand size.

3.2 Address Space and Memory

The address space of the 80960CA (Figure 3-2) is considered a subset of the execution environment since the code, data, data structures, and external peripherals for the processor reside here. The 80960 family has an address space which is 2^{32} bytes (4 Gbytes) in size. This address space is linear (unsegmented); therefore, code, data, and peripherals may be placed anywhere in the usable space. For the 80960CA, some memory locations are reserved or are assigned special functions as shown in Figure 3-2.

3.2.1 INTERNAL DATA RAM

The 80960CA provides 1 Kbyte of internal static RAM for fast access of frequently used data. The data RAM allows time critical data storage and retrieval, with no dependence on the performance of the external bus. Any load or store, including quad-word

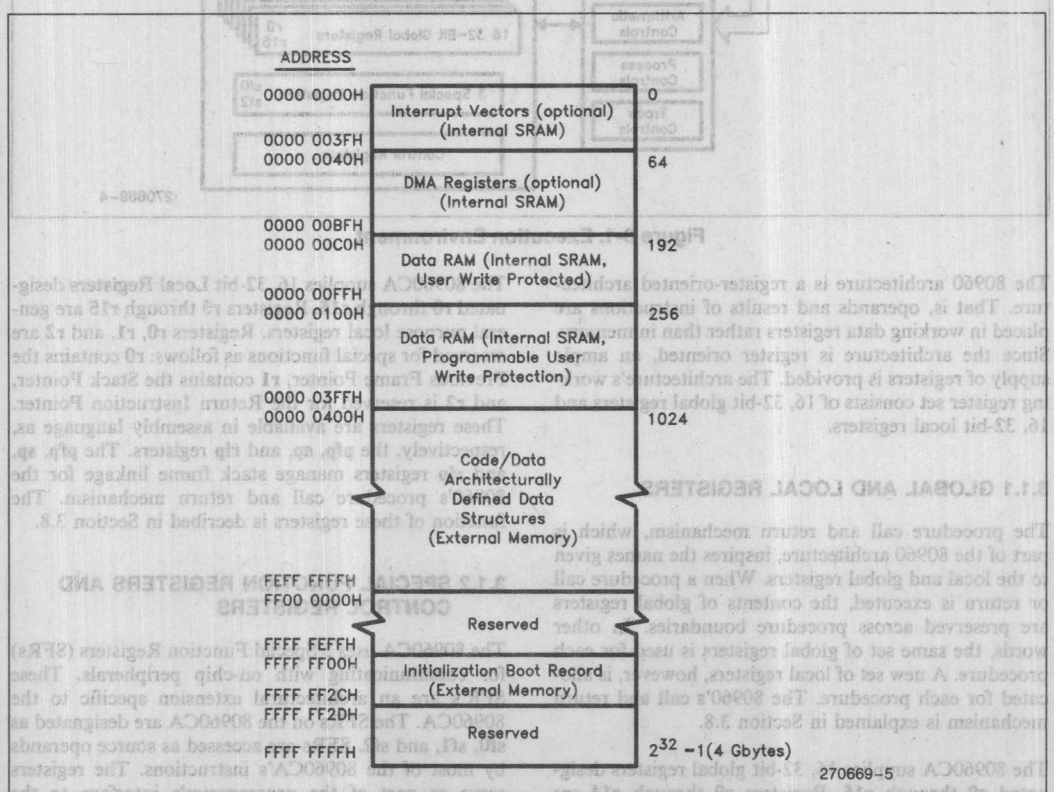


Figure 3-2. Address Space

operations, execute in a single clock cycle when directed to internal data RAM. The data RAM is located at address 00H in the processor's address space. When the DMA controller is in use, 32 bytes of data RAM are reserved for each active DMA channel. Additionally, 64 bytes of data RAM are reserved for 16 interrupt vectors which may be cached internally to reduce interrupt latency. The data RAM reserved for the DMA controller and the interrupt controller can be used for additional data storage when these peripherals are not used.

Two execution modes are possible on the 80960CA, *user mode* or *supervisor mode*. These modes are used to implement a protection model in which system data structures are isolated from user code. As shown in Figure 3-2, the first 256 bytes of data RAM are always write protected when a program is executing in user mode but may always be written when executing in supervisor mode. The remainder of the data RAM can be programmed for this protection feature. The user and supervisor modes are described further in Section 3.7.

3.2.2 RESERVED ADDRESS SPACE

The upper 16 Mbytes of memory (FF000000H–FFFFFFFFH) are reserved for specific functions and extensions to the 80960 architecture. The 12 words in reserved space (FFFFFF00H–FFFFFF2CH) are used to start up the processor when it comes out of reset. These 12 words are called the *initialization boot record*.

3.2.3 ARCHITECTURALLY DEFINED DATA STRUCTURES

To execute a program on the 80960CA, data structures specific to the 80960 architecture must reside in the processor's address space. Architecture-defined data structures include stacks, initialization structures, and various procedure entry tables. These data structures may generally be located anywhere in the address space. Pointers to each data structure are specified when the 80960CA is initialized. The architecture-defined data structures include:

- Interrupt Table
- System-Procedure Table
- Fault Table
- User Stack
- Interrupt Stack
- Supervisor Stack

In addition to the data structure defined by the architecture, the 80960CA requires several implementation-specific data structures which are used for configuring peripherals and initialization. These data structures include:

- Control Table
- Process Control Block
- Initialization Boot Record

Each data structure will be explained in more detail later in this product overview.

3.3 Memory Addressing Modes

The 80960CA offers a variety of modes for memory addressing. The addressing modes available are summarized in Table 3-1.

Absolute addressing is used to reference an address as an offset from address 0 of the processor's address space. At the machine level, absolute addressing may be implemented in one of two ways depending on the size of the absolute offset from address 0. Two instruction formats, MEMA and MEMB, are used to provide absolute addressing modes. For the MEMA format, the offset is an ordinal number ranging from 0 to 2048. For the MEMB format, the offset is an integer (called a displacement) ranging from $-2^{31}-1$ to 2^{31}. An assembler will choose the MEMA or MEMB format based on the size of the offset.

Register-indirect addressing modes use a 32-bit ordinal value in a register as the base for the address calculation. Offsets and indexes are added to this address base depending on the particular addressing mode. The *register-indirect-with-index* addressing mode adds a scaled index to the address base. The index is specified as a value in a register. The scale value may be selected as 1, 2, 4, 8, or 16.

The *index-with-displacement* addressing mode uses a scaled index plus an integer displacement. No address base is used in this address calculation.

The *IP-with-displacement* addressing mode is used with load and store instructions to make them IP relative. In this mode, an integer displacement plus a constant of 8 is added to the IP of the instruction to calculate the next address.

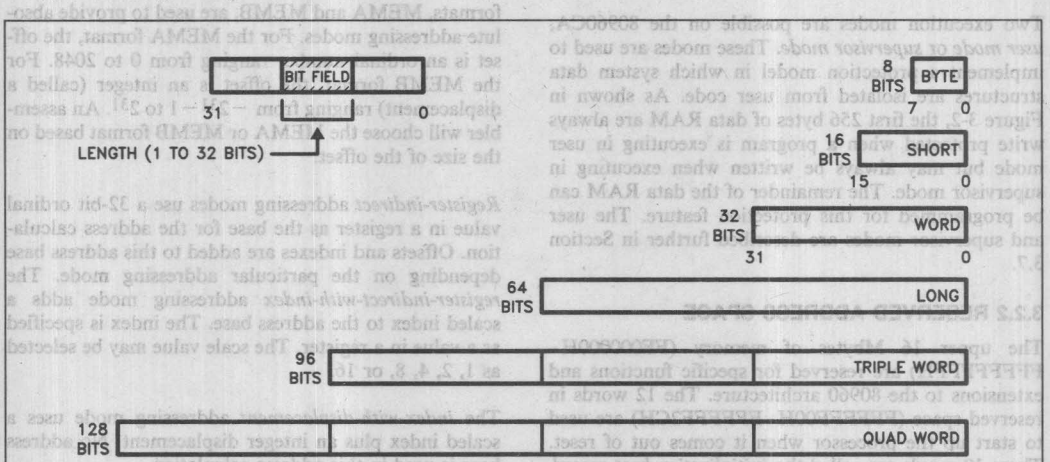
Table 3-1. Memory Addressing Modes

Mode	Description
Absolute Offset	Offset
Absolute Displacement	Displacement
Register Indirect	Abase
Register Indirect with Offset	Abase + Offset
Register Indirect with Index	Abase + (Index*Scale)
Register Indirect with Index and Displacement	Abase + (Index*Scale) + Displacement
Index with Displacement	(Index*Scale) + Displacement
Register Indirect with Displacement	Abase + Displacement
IP with Displacement	IP + Displacement + 8

3.4 Data Types

The 80960CA operates on the following data types (Figure 3-3):

— Integer (8, 16, 32, and 64 bits)
— Ordinal (8, 16, 32, and 64 bits)
— Bit
— Bit Field
— Triple Word (96 bits)
— Quad Word (128 bits)



Class	Data Type	Length	Range
Numeric (Integer)	Byte Integer	8 bits	-2^7 to $2^7 - 1$
	Short Integer	16 bits	-2^{15} to $2^{15} - 1$
	Integer	32 bits	-2^{31} to $2^{31} - 1$
	Long Integer	64 bits	-2^{63} to $2^{63} - 1$
Numeric (Ordinal)	Byte Ordinal	8 bits	0 to $2^8 - 1$
	Short Ordinal	16 bits	0 to $2^{16} - 1$
	Ordinal	32 bits	0 to $2^{32} - 1$
	Long Ordinal	64 bits	0 to $2^{64} - 1$
Non-Numeric	Bit	1-bit	N/A
	Bit Field	1–32 bits	
	Triple Word	96 bits	
	Quad Word	128 bits	

Figure 3-3. Data Types

The following sections describe the data types supported by the 80960CA.

3.4.1 NUMERIC DATA TYPES

Integers and ordinals are considered numeric data types since the processor performs arithmetic operations with this data. The integer data type is a signed binary value in standard 2's complement representation. The ordinal data type is an unsigned binary value.

3.4.2 NON-NUMERIC DATA TYPES

The remaining data types (bit field, triple word, and quad word) represent groupings of bits or bytes that the processor can operate on as a whole, regardless of the nature of the data contained in the group. These data types facilitate the moving of blocks of bits or bytes.

3.5 Instruction Set

The 80960CA features a comprehensive instruction set (Table 3-2). Much of the instruction set is that of a RISC architecture. Unlike pure RISC machines, however, the 80960CA provides an extension to the RISC instruction set with instructions that perform complex functions such as procedure calls and returns, high-speed multiplies, and other complex control, arithmetic, and logical operations. The instruction set allows functionally complex yet highly compact code to be written for embedded control applications where memory is a valuable commodity.

3.5.1 INSTRUCTION GROUPS

The 80960CA instruction set is most easily described if grouped by the functions listed below:

— Data Movement
— Address Computation
— Logical and Arithmetic
— Bit and Bit Field
— Comparison
— Branch
— Call and Return
— Fault
— Debug
— Processor Management

The instructions which make up each of these groups are described in the following sections.

3.5.1.1 Data Movement Instructions

The data movement instructions move data from memory to registers, from registers to memory, and between registers. The load instructions copy bytes, words, or multiple words from memory to a selected register or group of registers. Conversely, the store instructions copy bytes, words, or groups of words from a selected register or group of registers to memory. The move instructions copy data between registers.

Load Instructions

- **ld** load word
- **ldob** load ordinal byte
- **ldos** load ordinal short
- **ldib** load integer byte
- **ldis** load integer short
- **ldl** load long
- **ldt** load triple
- **ldq** load quad

Store Instructions

- **st** store word
- **stob** store ordinal byte
- **stos** store ordinal short
- **stib** store integer byte
- **stis** store integer short
- **stl** store long
- **stt** store triple
- **stq** store quad

Move Instructions

- **mov** move word
- **movl** move long
- **movt** move triple
- **movq** move quad

3.5.1.2 Address Computation Instructions

The load address (**lda**) instruction causes a 32-bit address to be computed and placed in a destination register. The address is computed based on the addressing mode selected. The load and store instructions perform a function identical to that of the **lda** instruction when calculating a source or destination address. The **lda** instruction is useful for loading a 32-bit constant into a register.

3.5.1.3 Logical and Arithmetic Instructions

Logical instructions perform bitwise Boolean operations on operands in registers. Since this group of instructions performs only bitwise manipulations of data, separate logical instructions for integer and ordinal data types do not exist. In the table below, src1 and src2 represent processor registers or literals which are the operands for these instructions.

Table 3-2. Instruction Set Summary

Data Movement	Arithmetic	Logical	Bit and Bit Field
Load Store Move	Add Subtract Multiply Divide Remainder Modulo Shift Extended Shift Extended Multiply Extended Divide Add with Carry Subtract with Carry	And Not And And Not Or Exclusive Or Not Or Or Not Nor Exclusive Nor Not Nand Rotate	Set Bit Clear Bit Not Bit Check Bit Alter Bit Scan for Bit Scan for Byte Span over Bit Extract Modify
Comparison	**Branch**	**Call and Return**	**Fault**
Compare Condition Compare Compare and Increment Compare and Decrement Condition Test	Unconditional Branch Conditional Branch Branch and Link Condition Compare and Conditional Branch	Call Call Extended Call System Return	Conditional Fault Synchronize Faults
Debug	**Processor Management**	**Address Computation**	**Atomic**
Modify Trace Controls Mark Force Mark	Modify Process Controls Modify Arithmetic Controls System Control Update DMA Setup DMA Flush Local Registers	Load Address	Atomic Add Atomic Modify

Logical Instructions

- **and** src1 and src2
- **notand** src1 and (not src2)
- **andnot** (not src1) and src2
- **or** src1 or src2
- **notor** src1 or (not src2)
- **ornot** (not src1) or src2
- **xor** src1 xor src2
- **xnor** src1 xnor src2
- **nor** not (src1 or src2)
- **nand** not (src1 and src2)
- **not** not (src1)

Arithmetic instructions perform add, subtract, multiply, divide, and shift operations on integer or ordinal operands in registers.

Arithmetic Instructions

- **addi** add integer
- **addo** add ordinal
- **subi** subtract integer
- **subo** subtract ordinal
- **muli** multiply integer
- **mulo** multiply ordinal
- **divi** divide integer
- **divo** divide ordinal
- **remi** remainder integer
- **remo** remainder ordinal
- **modi** modulo integer
- **rotate** rotate bit left
- **shli** shift left integer
- **shlo** shift left ordinal
- **shri** shift right integer
- **shro** shift right ordinal
- **shrdi** shift right dividing integer

Extended arithmetic instructions facilitate computation on ordinals and integers which are longer than 32 bits. In add with carry and subtract with carry instructions, the carry out from the previous arithmetic instruction is used in the computation. The extended multiply instruction multiplies two ordinal source operands producing a long ordinal result (64 bits). The extended divide instruction divides a long ordinal dividend by an ordinal divisor and produces a 64-bit result. The extended shift right instruction shifts a 64-bit source value and produces the lower order 32 bits of the shifted value.

Extended Arithmetic Instructions

- **addc** add ordinal with carry
- **subc** subtract ordinal with carry
- **emul** extended multiply
- **ediv** extended divide
- **eshro** shift right extended ordinal

The atomic instructions perform read-modify-write operations on operands in memory. They allow a system to insure that when an atomic operation is performed on a specified memory location, the operation will be completed before another agent is allowed to perform an operation on the same memory. These instructions are required to enable synchronization between interrupt handlers and background tasks in any system. They are also particularly useful in systems where several agents (processors, coprocessors, or external logic) have access to the same system memory for communication.

Atomic Instructions

- **atadd** atomic add
- **atmod** atomic modify

3.5.1.4 Bit and Bit Field Instructions

The bit instructions operate on a specified bit in a register.

Bit Instructions

- **setbit** set bit
- **clrbit** clear bit
- **notbit** not bit
- **alterbit** alter bit
- **scanbit** scan for bit
- **spanbit** span over bit

Bit field instructions operate on a specified contiguous group of bits in a register. This group of bits can be from 0 to 32 bits in length.

Bit Field Instructions

- **extract** extract field
- **modify** modify field
- **scanbyte** scan for byte

3.5.1.5 Branch Instructions

The branch instructions allow the direction of program flow to be changed by explicitly modifying the *Instruction Pointer (IP)*. The target IP in a branch instruction is generally specified as a displacement to be added to the current IP. The extended branch instructions allow IP calculation using any addressing mode.

The unconditional branch instructions always alter program flow when executed.

Unconditional Branch Instructions

- **b** branch
- **bx** branch extended

The RISC branch-and-link instructions automatically save a Return Instruction Pointer (RIP) before the

jump is taken. The RIP is the address of the instruction following the branch and link.

Branch and Link Instructions

- **bal** branch and link
- **balx** branch and link extended

Conditional branch instructions alter program flow only if the *condition code flags* in the arithmetic control register match a value specified in the instruction. The condition code flags indicate conditions of equality or inequality between two operands in a previously executed instruction. The arithmetic control register and condition code flags are described in Section 3.6.

Based on a *branch prediction flag* located in the machine level instruction, the 80960CA will assume that an instruction usually takes or does not take a conditional branch. By executing along the predicted path of program flow, delays due to breaks in the instruction stream are often avoided. This feature of the 80960CA is referred to as *branch prediction*. The 80960CA incorporates the branch prediction feature because code using a conditional branch instruction usually favors a single direction of program flow.

The branch prediction flag is specified at the assembly level by appending a *.t* or *.f* to a conditional branch instruction meaning, respectively, "assume branch taken" or "assume branch not taken". For example, the assembler mnemonic **be.t** means that the processor will assume that this branch-if-equal instruction usually branches when encountered. In the following table .p represents the branch prediction flag.

Conditional Branch Instructions

- **be.p** branch if equal
- **bne.p** branch if not equal
- **bl.p** branch if less
- **ble.p** branch if less or equal
- **bg.p** branch if greater
- **bge.p** branch if greater or equal
- **bo.p** branch if ordered
- **bno.p** branch if unordered

Compare and conditional branch instructions compare two operands, then branch according to the immediate results.

Conditional Compare and Conditions Branch Instructions

- **cmpibe.p** compare integer and branch if equal
- **cmpibne.p** compare integer and branch if not equal
- **cmpibl.p** compare integer and branch if less
- **cmpible.p** compare integer and branch if less or equal
- **cmpibg.p** compare integer and branch if greater
- **cmpibge.p** compare integer and branch if greater or equal
- **cmpibo.p** compare integer and branch if ordered
- **cmpibno.p** compare integer and branch if unordered
- **cmpobe.p** compare ordinal and branch if equal
- **cmpobne.p** compare ordinal and branch if not equal
- **cmpobl.p** compare ordinal and branch if less
- **cmpoble.p** compare ordinal and branch if less or equal
- **cmpobg.p** compare ordinal and branch if greater
- **cmpobge.p** compare ordinal and branch if greater or equal
- **bbs.p** check bit and branch if set
- **bbc.p** check bit and branch if clear

3.5.1.6 Compare and Condition Test Instructions

The 80960CA provides several types of instructions that are used to compare two operands. The condition code flags in the arithmetic control register are set to indicate whether one operand is less than, equal to, or greater than the other operand.

Compare Instructions

- **cmpi** compare integer
- **cmpo** compare ordinal
- **chkbit** check bit

Conditional compare instructions test the existing status of the condition code flags before a compare is

performed. These conditional compare instructions are provided to optimize two-sided range comparisons (i.e. to test if a value is less than one number but greater than another).

Conditional Compare Instructions

- concmpi	conditional compare integer
- concmpo	conditional compare ordinal

The compare and increment and compare and decrement instructions set the condition code flags based on a comparison of two register sources, decrements or increments one of the sources, and finally stores this result in a destination register.

- cmpinci	compare and increment integer
- cmpinco	compare and increment ordinal
- cmpdeci	compare and decrement integer
- cmpdeco	compare and decrement ordinal

The condition test instructions allow the state of the condition code flags to be tested. Based on the outcome of the comparison, a true or false code is stored in a destination register. The branch prediction flag is used in this instruction to reduce the execution time of the instruction when the test outcome is predicted correctly. For example **teste.t** (test if equal) will execute in a shorter time if the condition code flags test true for the equal condition. Analogous to the function of the branch prediction flag in the conditional compare and branch instructions, the prediction flag in this case eliminates breaks in the micro-instruction sequence which is used to implement the condition test instructions.

Condition Test Instructions

- teste.p	test if equal
- testne.p	test if not equal
- testl.p	test if less
- testle.p	test if less or equal
- testg.p	test if greater
- testge.p	test if greater or equal
- testo.p	test if ordered
- testno.p	test if not ordered

3.5.1.7 Call and Return Instructions

The 80960CA features an on-chip call and return mechanism for making procedure calls to local and system procedures. The call instructions and the call and return mechanism is described in Section 3.8.

Call and Return Instructions

- call	call
- callx	call extended
- calls	call system
- ret	return

3.5.1.8 Fault Instructions

The 80960CA will fault automatically as the result of certain errant operations which may occur when executing code. Fault procedures are then invoked automatically to handle the various types of faults. In addition, the fault instructions permit a fault to be generated explicitly based on the value of the condition code flags. The branch prediction flag in these instructions is used to reduce the execution time of these instructions when the state of the condition code flags are guessed correctly.

Conditional Fault Instructions

- faulte.p	fault if equal
- faultne.p	fault if not equal
- faultl.p	fault if less
- faultle.p	fault if less or equal
- faultg.p	fault if greater
- faultge.p	fault if greater or equal
- faulto.p	fault if ordered
- faultno.p	fault if unordered

The **syncf** instruction causes the processor to wait for all faults to be generated which are associated with any prior uncompleted instructions.

- syncf	synchronize faults

3.5.1.9 Debug Instructions

The processor supports debugging and monitoring of program activity through the use of trace events. The debug instructions support debugging and monitoring software.

Debug Instructions

- modtc	modify trace controls
- mark	mark
- fmark	force mark

3.5.1.10 Processor Management Instructions

The 80960CA provides several instructions for direct control of processor functions and for configuring the 80960CA's peripherals. A brief description of the processor management instructions is given below.

Processor Management Instructions

- modpc	modify process controls
- modac	modify arithmetic controls
- sysctl	system control instruction
- udma	update DMA SRAM
- sdma	setup DMA
- flushreg	flush local registers

3.6 Arithmetic Controls

The *Arithmetic Control (AC) Register* is a 32-bit on-chip register (Figure 3-4). The AC register is used primarily to monitor and control the execution of 80960CA arithmetic instructions. The processor reads and modifies bits in the AC register when performing many arithmetic operations. The AC register is also used to control the faulting conditions for some instructions. The **modac** instruction allows the user to directly read or modify the AC register.

The processor sets the condition code flags (bits 0–2) to indicate equality or inequality as the result of certain instructions (such as the compare instructions). Other instructions, such as the conditional branch instructions, take action based on the value of the condition code flags. Table 3-3 shows the functional assignment for each condition code flag.

Table 3-3. Arithmetic Condition Codes

Condition Code	Condition
001	Greater Than
010	Equal
100	Less Than

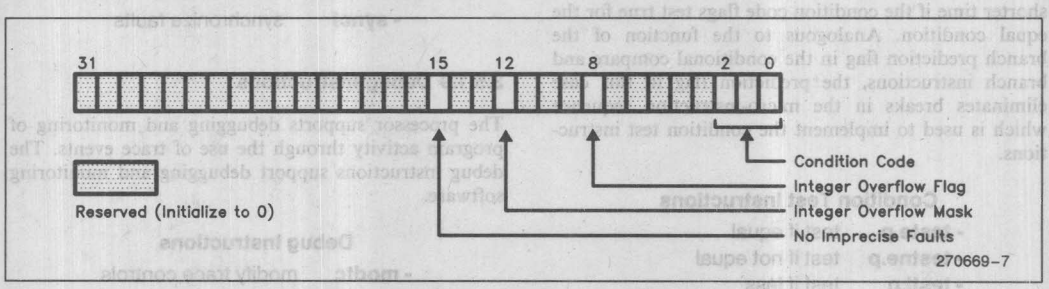


Figure 3-4. Arithmetic Control Register

The integer overflow flag (bit 8) and the integer overflow mask (bit 12) are used in conjunction with the arithmetic integer overflow fault. The mask bit masks the integer overflow fault. When the fault is masked, and an integer overflow occurs, the integer overflow flag is set but no fault handling action is taken. If the fault is not masked, and an integer overflow occurs, the integer overflow fault is taken and the integer overflow flag is not set.

The no imprecise faults flag (bit 15) determines if imprecise faults are allowed to occur. Fault handling and precise and imprecise faults in the 80960CA are discussed in Section 3.10.

3.7 Process Management

Process management refers to the monitoring and control of certain properties of an executing process. The following sections describe the mechanisms available on the 80960CA to perform this function.

3.7.1 PROCESS CONTROL REGISTER

The *Process Control (PC) Register* (Figure 3-5) provides access to process state information. The function for the PC register is described below.

Execution Mode Flag—This flag indicates that the processor is executing in user mode (0) or supervisor mode (1).

Priority Field—This 5-bit field indicates the current executing priority of the processor. Priority values range from 0 to 31, with 0 as the lowest and 31 as the highest priority.

State Flag—This flag determines the executing state of the processor. The processor state is either executing state (0) or interrupted state (1).

Trace Enable Bit and Trace Fault Pending Flags—These fields control and monitor trace activity in the processor. The Trace Enable Bit enables fault generation for trace events. The Trace Fault Pending Flag indicates that a trace event has been detected.

The process controls can be modified by software with the modify process controls (**modpc**) instruction. The **modpc** instruction may only write the PC register when the processor is in supervisor mode.

3.7.2 PRIORITIES

The 80960 architecture defines a means to assign priorities to executing programs and interrupts. The current priority of the processor is stored in the priority field of the PC register. This priority is used to determine if an interrupt will be serviced and in which order multiple pending interrupts will be serviced. Setting the priority of an executing program above that of interrupts allows critical code to be prioritized and executed without interruption.

The priority field of the PC register can be modified directly using the **modpc** instruction. The priority field is also modified to reflect the priority of serviced interrupts. On a return from an interrupt routine, the priority of the processor is restored to its priority before the interrupt occurred.

3.7.3 PROCESSOR STATES AND MODES

The 80960CA may execute programs in *user mode* or *supervisor mode*. The user-supervisor protection mechanism allows a system to be designed in which kernel code and data reside in the same address space as user code and data, but access to the kernel procedures and data is only allowed through a tightly controlled interface. This interface is the system call table and the interrupt mechanism. The 80960CA provides a supervisor pin ($\overline{SUP}$) to implement memory systems which protect code and data from possible corruption by programs executing in user mode. Some instructions and functions of the 80960CA are also insulated from code executing in user mode.

The processor has two operating states: executing and interrupted. In executing state, the processor can execute in user or supervisor mode. In the interrupted state, the processor always executes in supervisor mode.

3.8 Call and Return Mechanism

The 80960 architecture features a built-in call and return mechanism. This mechanism is designed to make procedure calls simple and fast, and to provide a flexible method for storing and handling variables that are local to a procedure. A call automatically allocates a new set of local registers and a new stack frame. All linkage information is maintained by the processor, making procedure calls and returns virtually transparent to the user. A system call instruction is provided as a method for calling privileged procedures such as a kernel service. The call and return model supports efficient translation of structured high level code (such as C, or ADA) to 80960 machine language.

The procedure call and return mechanism provides a number of significant benefits which contribute to the performance and ease of use of the 80960CA.

1) The call and return instructions are implemented entirely on-chip, resulting in an extremely high performance implementation of these commonly used functions.

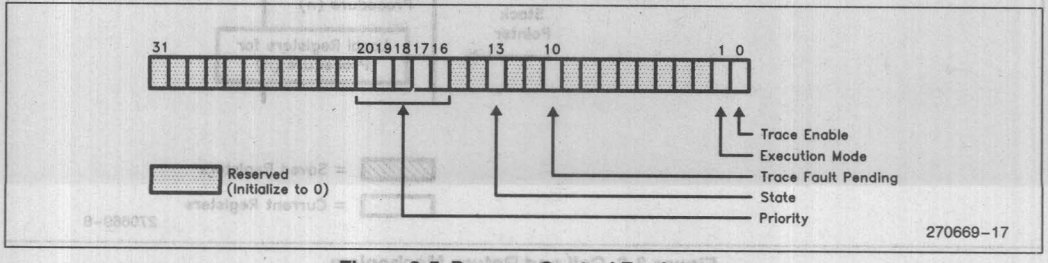


Figure 3-5. Process Control Register

2) A single instruction to implement each call or return operation results in code density improvements compared to processors which require multiple instructions to encode these functions.
3) By implementing the call and return functions as single instructions, the 80960 architecture is open for further optimization of these instructions, while maintaining assembly-level compatibility.
4) A program does not have to explicitly save or restore the variables stored in the local registers when a call or return is executed. The processor does this implicitly on procedure calls and on returns.
5) The call and return mechanism provides a structure for storing a virtually unlimited number of local variables for each procedure: the on-chip local registers provide quick access to often used variables and the stack provides space for additional variables.

3.8.1 LOCAL REGISTERS AND THE STACK FRAME

At any point in a program, the 80960 has access to a local register set and a section of the procedure stack referred to as a stack frame. When a call is executed, a new stack frame is allocated for the called procedure. Additionally, the current local register set is saved by the processor, freeing these registers for use by the newly called procedure. In this way, every procedure has a unique stack and unique set of local registers. When a return is executed, the current local register set and current stack frame are deallocated. The previous local register set and previous stack frame are restored. This call and return mechanism is illustrated in Figure 3-6 where n is procedure depth for the currently executing procedure.

The procedure stack structure is defined by the 80960 architecture. The procedure stack always grows upward (i.e. towards higher addresses) and the stack pointer (SP) always points to the next available byte of the stack frame. The 80960CA requires that each stack frame begins on a 16-byte boundary. Due to this alignment requirement, a padding space of 0 to 15 bytes may exist between adjacent stack frames in memory. When a stack frame is allocated, the first 16 words are always assigned as storage for the local registers; therefore, the SP initially points to the 17th word in the stack frame. It should be noted that although each stack frame is assigned storage space for the local registers, these locations in the stack are not guaranteed to contain the values of the saved local registers. This is because several sets of local registers are cached on-chip rather than written to the stack in external memory. This caching mechanism is described in detail later in this section.

3.8.2 PROCEDURE LINKING

The 80960 architecture automatically manages procedure linkage. One global register and three local registers are reserved for procedure linkage information.

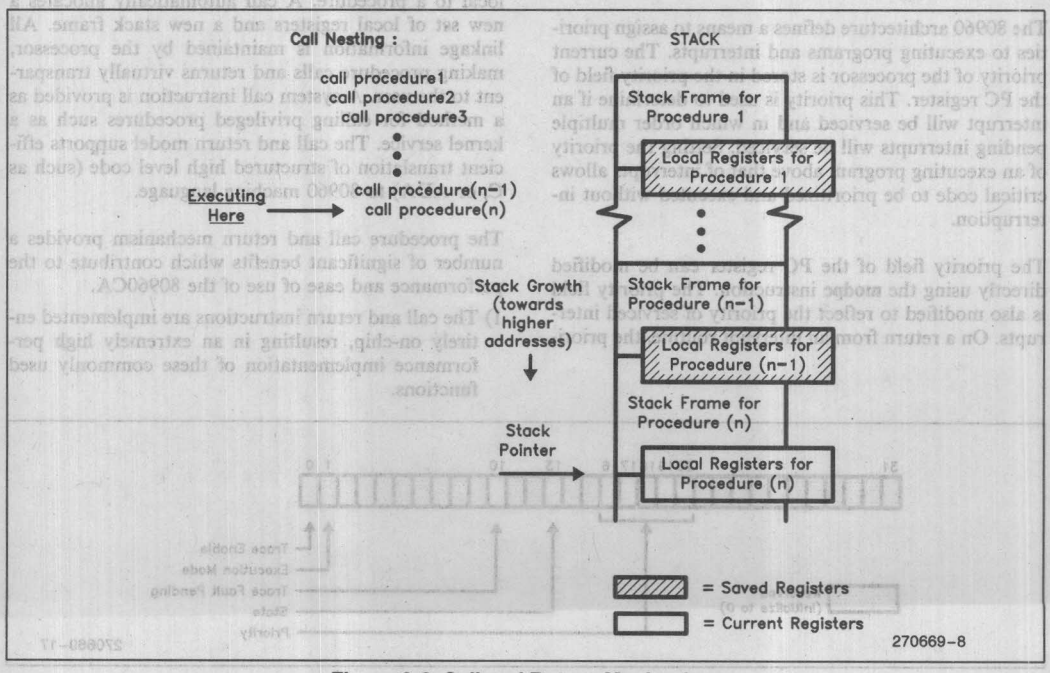


Figure 3-6. Call and Return Mechanism

Figure 3-7 describes the pointer structure used to link frames and to provide a unique SP for each frame. Register **g15** is the *Frame Pointer (FP)*. The FP is the address of the first byte of the current (topmost) stack frame. The FP is always updated to point to the current frame when calls and returns are executed. Register **r0** is the *Previous Frame Pointer (PFP)*. The PFP is the address of the first byte of the stack frame which was created prior to the frame containing this PFP. Register **r1** is the *Stack Pointer (SP)*. The SP points to the next available byte of the stack frame. Register **r2** is reserved for the *Return Instruction Pointer (RIP)*. The RIP is the address of the instruction which follows a call instruction, this is also the target address for the return from that procedure. The RIP is automatically stored in register **r2** of the calling procedure when a call is executed.

3.8.3 PARAMETER PASSING

Parameters may be passed by value or passed by reference between procedures. The global registers, the stack, or predefined data structures in memory may be used to pass these parameters.

The global registers provide the fastest method for passing parameters. The values to be passed into a procedure reside in the global registers of the calling procedure. When a procedure is called, the values in the global registers are preserved. If more parameters are to be passed than will fit in the global registers, additional parameters may be passed in the stack of the calling procedure, or in a data structure which is referenced by a pointer passed in the global registers.

3.8.4 LOCAL REGISTER CACHE

The 80960CA provides an on-chip cache for saving and restoring the local registers on calls and returns. This cache greatly enhances performance of the call and return mechanism on the 80960CA. Movement of data between the local registers and the register cache is typically accomplished in only 4 processor clocks with no external bus traffic. When this cache is filled, the registers associated with the oldest stack frame are moved to the area reserved for those registers on the physical stack (Figure 3-7).

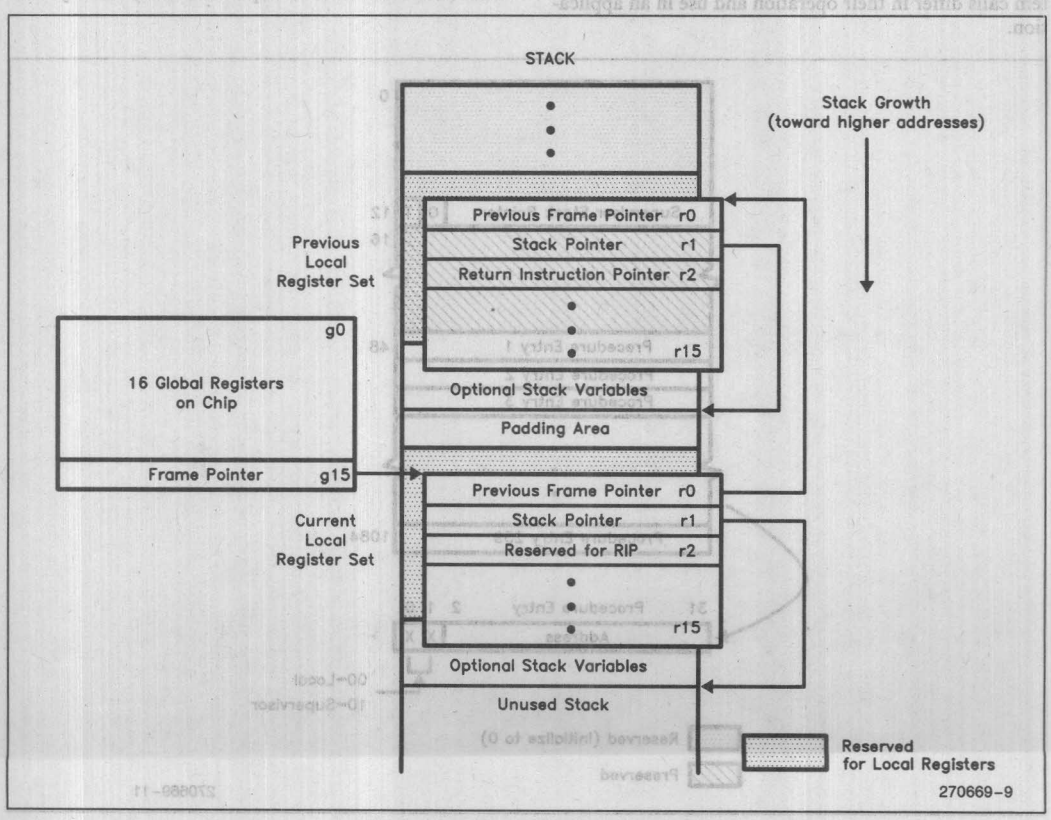


Figure 3-7. Stack Frame Linkage

The local register cache is a physical extension of the internal data RAM. The part of the data RAM used for this cache is not visible to the user and is large enough to hold up to 5 sets of local registers. The register cache may be extended to hold up to 15 sets of local registers. When extended, each new register set consumes 16 words of the user's data RAM, beginning at the highest address and growing downward. The size of the local register cache is selected when the processor is initialized.

In some cases, the contents of the cached local register sets may require examination or modification (e.g. for fault handling). Since the local registers are cached, the **flushreg** instruction is provided to flush the local register cache to the locations reserved for the registers on the stack. This insures that the values in external memory are consistent with the values held in the local register cache.

3.8.5 LOCAL AND SYSTEM CALLS

The 80960CA provides two methods for making procedure calls: local calls and system calls. Local and system calls differ in their operation and use in an application.

The local call instructions initiate a procedure call using the call and return mechanism described earlier. The stack frames for these procedure calls are allocated on the *local procedure stack*. A local call is made using either of two local call instructions: **call** or **callx**. The **call** instruction specifies the address of the called procedure using an IP plus displacement addressing mode with a range of -2^{23} to $2^{23}-4$ bytes from the current IP. The **callx** (call extended) instruction specifies the address of the calling procedure using any of the 80960's addressing modes.

A system call is made using the **calls** instruction. This call is similar to a local call except that the processor gets the IP for the called procedure from a data structure called the *system procedure table*. The **calls** instruction requires a procedure number operand. This procedure number serves as an index into the system procedure table, which contains IP's for specific procedures. The system procedure table is shown in Figure 3-8.

The system call mechanism supports two types of procedure calls: system-local calls and system-supervisor calls (also referred to as supervisor calls). The system-

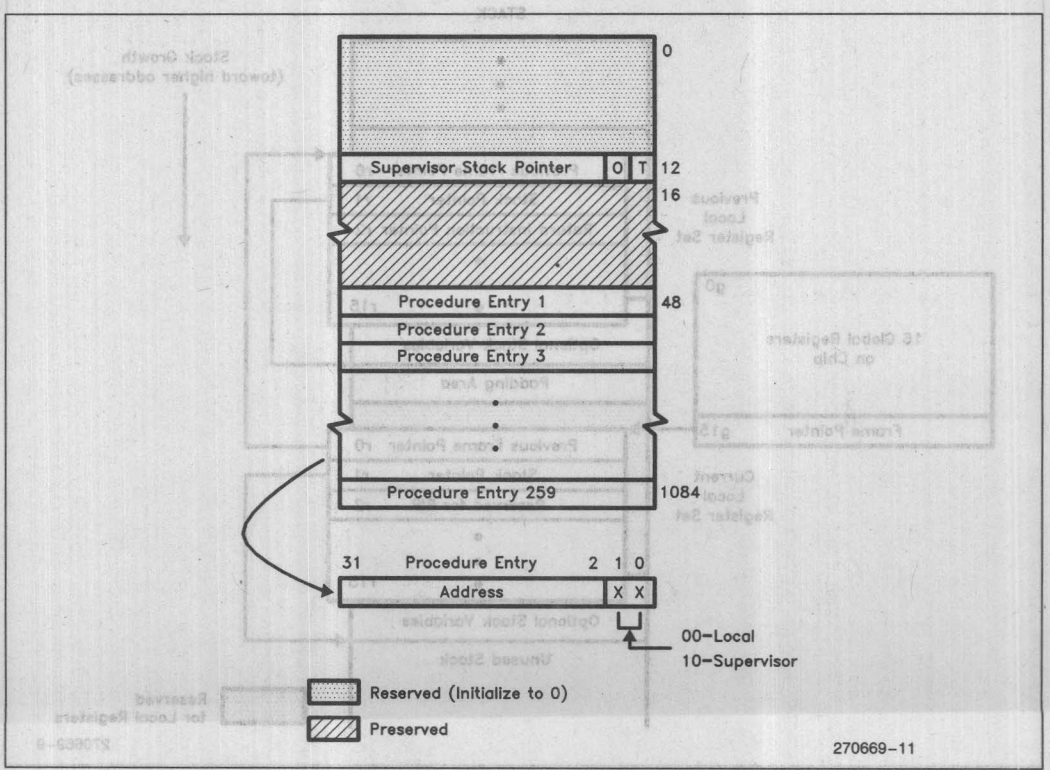


Figure 3-8. System Procedure Table

local call performs the same action as the local call instructions with one exception: the IP target for a system-local call is fetched from the system-procedure table. The supervisor call differs from the local call as follows:

1) A supervisor call causes the processor to switch to another stack (called the supervisor stack).
2) A supervisor call causes the processor to switch to the supervisor execution mode and asserts the 80960CA's supervisor ($\overline{SUP}$) pin for all bus accesses.

The system call mechanism offers several benefits. The system call promotes the portability of application software. System calls are commonly used for kernel services. By calling these services with a procedure number rather than a specific IP, application software does not have to be changed each time the implementation of the kernel service is modified. Additionally, the ability to switch to a different execution mode and stack allows kernel procedures and data to be insulated from application code.

3.8.6 IMPLICIT PROCEDURE CALLS

The call and return mechanism described for procedure calls applies to several classes of call instructions as well as to the context switching initiated by interrupts and faults. When an interrupt or fault condition occurs, an implicit call is performed that saves the current state of the processor before branching to the interrupt or fault handling procedure. When this context switch occurs, the local registers are saved and a new stack frame is allocated. Additionally, the values of the AC register and PC register are saved when the implicit call occurs. These values are restored on the return from the interrupt or fault handler.

3.9 Interrupts

An interrupt is a temporary break in the control stream of a program so that the processor can handle another task. Interrupts may be triggered by the instruction stream or by hardware sources internal and external to the 80960CA. An interrupt request is associated with a vector (i.e. an address) of an interrupt handling procedure. The processor will branch to the handling procedure when an interrupt is serviced. When the handling action is completed, the processor is restored to its state prior to the interrupt.

3.9.1 INTERRUPT VECTORS AND PRIORITY

Interrupt vectors are simply instruction pointers (addresses) to interrupt handling procedures. The 80960 architecture defines 248 interrupt vectors. This means that 248 unique interrupt handling procedures may be used. An 8-bit interrupt vector number is associated with each interrupt vector. This number ranges from 8 to 255. Each interrupt vector has a priority from 1 to 31, which is determined by the 5 most significant bits of the interrupt vector number. Priority 1 is the lowest priority and 31 is the highest. Priority 0 interrupts are not defined.

The 80960CA executes with a unique priority ranging from 0 to 31. When an interrupt is serviced, the processor's priority switches to the priority corresponding to that of the interrupt request. When a return from an interrupt procedure is executed, the process priority is restored to its value prior to servicing the interrupt. This priority switching is handled automatically by the 80960CA.

The 80960CA compares its current priority and the priority of an interrupt request to determine whether to service an interrupt immediately or to delay service. If a requested interrupt priority is greater than the processor's current priority or equal to 31, the processor services the interrupt immediately; otherwise, the processor saves (posts) the interrupt request as a pending interrupt so that it can be serviced later. When the processor's priority falls below the priority of a pending interrupt, the pending interrupt is serviced. With the mechanism described, interrupts with a priority of 0 will never be serviced. For this reason, vectors numbered 0 to 7 are not defined.

3.9.2 INTERRUPT TABLE

The interrupt table (Figure 3-9) is an architecturally defined data structure which holds the interrupt vectors and information on pending interrupts. The first 36 bytes of the table are used to post interrupts. The 31 most significant bits in the 32-bit pending priorities field represent a possible priority (1 to 31) of a pending interrupt. When the processor posts an interrupt in the interrupt table, the bit corresponding to the interrupt's priority is set. For example, if an interrupt with a priority of 10 is posted in the interrupt table, bit 10 is set in the pending priorities field.

The pending interrupts field contains a 256-bit string in which each bit represents an interrupt vector. When the processor posts an interrupt in the interrupt table, the bit corresponding to the vector number of that interrupt is set.

Portions of the interrupt table are cached on-chip in a non-transparent fashion. This caching is implemented to minimized interrupt latency by reducing the number of accesses to the table in external memory when an interrupt is serviced.

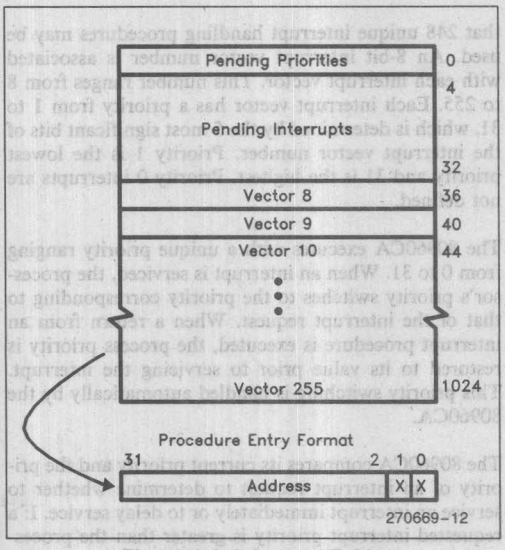


Figure 3-9. Interrupt Table

3.9.3 INTERRUPT STACK

Stack frames for interrupt handling procedures are allocated on a separate *interrupt stack*. The interrupt stack can be located anywhere in the processor's address space. The beginning address of the interrupt stack is specified when the processor is initialized.

3.9.4 INTERRUPT HANDLING ACTION

When an interrupt is serviced, the processor saves the processor state and calls the interrupt procedure. The processor state is restored upon return from the interrupt procedure.

This interrupt service mechanism is handled by an implicit call operation. When the interrupt is serviced, the current local registers are saved. A new local register set and stack frame are allocated on the interrupt stack for the interrupt handler procedure and the processor switches to supervisor execution mode. In addition to the local registers, the current value of the AC and PC registers are saved as an interrupt record on the interrupt stack.

3.9.5 PENDING INTERRUPTS

Any of the 248 interrupts can be requested by software. The system control instruction (**sysctl**) is provided to support this feature. When the system control instruction requests an interrupt, one of two actions may occur depending on the priority of the requested interrupt and the current process priority. 1) The interrupt is serviced immediately, or 2) the interrupt is posted (the pending priorities field and the pending interrupts field are modified to reflect a pending interrupt).

Interrupts may also be requested by hardware sources internal and external to the 80960CA. Managing the hardware sources and posting these interrupts is handled by the interrupt controller. Interrupts requested by hardware are posted in an internal register, not in the interrupt table. A mask register enables or disables interrupts from each hardware source. Requesting and posting hardware interrupts is described in Section 4.4 Interrupt Controller.

3.9.6 INTERRUPT LATENCY

The time required to perform an interrupt task switch is referred to as the *interrupt latency*. The latency is the time measured between the activation of an interrupt source and the execution of the first instruction for the interrupt-handling procedure for the source.

Interrupt latency for the 80960CA varies depending on conditions such as:

— Complex instructions are executing when the interrupt occurs (e.g. **sysctl, call, ret,** etc.).

— Outstanding loads to a local register are pending, delaying the interrupt context switch.

— Division, multiplication, or other multi-cycle instructions with a local register as destination are executing.

The 80960CA has been designed to optimize latency and throughput for interrupts. Two processor features are designed for this purpose:

First, in the interrupt table, all interrupt vectors with an index whose least significant four bits are 0010_2 can be cached in internal data RAM. The processor will automatically read these vectors from data RAM when the interrupt is serviced. This feature reduces the added latency due to an external access of the interrupt table for that vector. The NMI vector is always cached in data RAM.

Second, an instruction cache locking mechanism allows interrupt procedures or segments of interrupt procedures to be stored in the instruction cache. These routines are always executed from the internal cache, eliminating external code fetches and reducing latency and increasing throughput for the interrupt.

3.10 Fault Handling and Instruction Tracing

The 80960CA is able to detect various conditions in code or in its internal state that could cause the processor to deliver incorrect or inappropriate results or that could cause it to head down an undesirable control path. These conditions are referred to as faults. The 80960 architecture provides fault handling mechanisms to detect and, in most cases, fully recover from a fault.

The 80960CA provides on-chip debug support by triggering trace events and servicing the trace fault. A trace event is activated when a particular instruction or type of instruction is encountered in an instruction stream. The trace event optionally signals a fault. A fault handling procedure for the trace fault can act as a debug monitor and analyze the state of the processor when the trace event occurred.

3.10.1 FAULT TYPES AND SUBTYPES

All of the faults that the processor detects are predefined. These faults are divided into types and subtypes, each of which is given a number. Table 3-4 lists the faults that the processor detects arranged by type and subtype.

Table 3-4. Fault Types and Subtypes

Fault Type	Fault Subtype	Fault Record
Parallel		XX00 00XX
Trace	Instruction Type	XX01 0002
	Branch Trace	XX01 0004
	Call Trace	XX01 0008
	Return Trace	XX01 0010
	Prereturn Trace	XX01 0020
	Supervisor Trace	XX01 0040
	Breakpoint Trace	XX01 0080
Operation	Invalid Opcode	XX02 0001
	Unimplemented	X002 0002
	Invalid Operand	XX02 0004
Arithmetic	Integer Overflow	XX03 0001
	Arithmetic Zero-Divide	XX03 0002
Constraint	Range	XX05 0001
	Privileged	XX05 0002
Protection	Length	XX07 0001
Type	Mismatch	XX0A 0001

NOTE: X refers to preserved locations in the fault record.

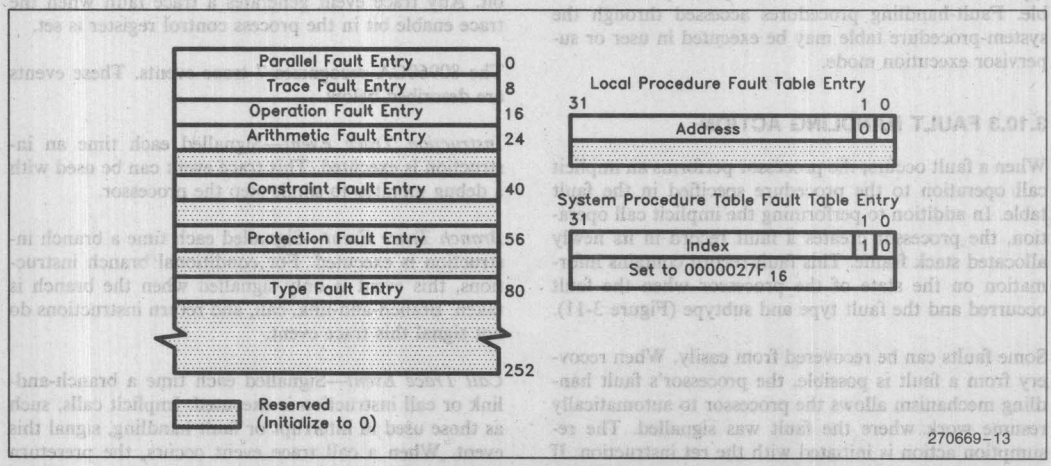


Figure 3-10. Fault Table

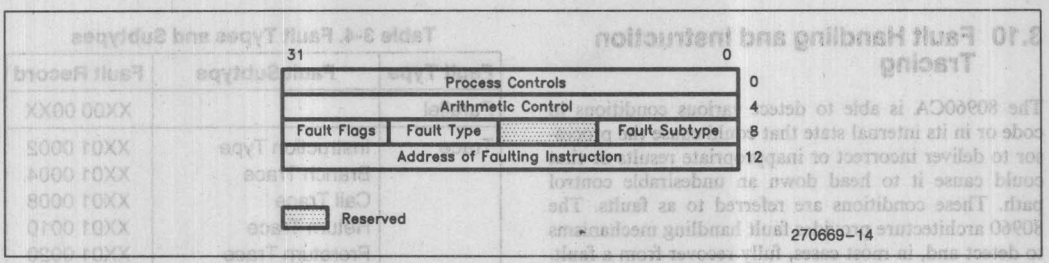


Figure 3-11. Fault Record

3.10.2 FAULT TABLE

The fault table (Figure 3-10) provides the processor with a pathway to fault handling procedures. The fault table is an architecture-defined data structure, which may be located anywhere in the processor's address space. The location of the fault table is specified at initialization. When a fault occurs, an entry in the table is selected based on the type of fault that occurs. The entry in the fault table contains a pointer to a specific fault handler.

The fault table can contain two types of entries (Figure 3-10). The first type of entry is simply a pointer to the address of the fault-handling procedure. The second type of entry is an index into the system-procedure table. Fault-handling procedures accessed through the system-procedure table may be executed in user or supervisor execution mode.

3.10.3 FAULT HANDLING ACTION

When a fault occurs, the processor performs an implicit call operation to the procedure specified in the fault table. In addition to performing the implicit call operation, the processor creates a fault record in its newly allocated stack frame. This fault record contains information on the state of the processor when the fault occurred and the fault type and subtype (Figure 3-11).

Some faults can be recovered from easily. When recovery from a fault is possible, the processor's fault handling mechanism allows the processor to automatically resume work where the fault was signalled. The resumption action is initiated with the **ret** instruction. If simple recovery from a fault is not possible, then the fault handling procedure may call a debug monitor, initiate a reset, or take other actions to recover from the fault.

3.10.4 TRACING AND DEBUG

The 80960CA provides a facility for monitoring the activity of the processor by tracing the instruction stream. A trace event occurs at points in a program where certain types of instructions are encountered or a certain IP or data address is encountered. When a trace event occurs, a trace fault can be generated and a trace-fault handler called which displays or analyzes the state of the processor.

3.10.4.1 Trace Events

The *Trace Control (TC) Register* (Figure 3-12) is used to specify the types of instructions which cause trace events. When a mode bit in the TC register is set, specific instructions will generate trace events. For example, if the branch trace mode bit is enabled and a branch instruction is executed, a branch trace event will be signalled. An event flag is used to record trace events. A single event flag is provided for each mode bit. Any trace event generates a trace fault when the trace enable bit in the process control register is set.

The 80960CA recognizes 7 trace events. These events are described below.

Instruction Trace Event—Signalled each time an instruction is executed. This trace event can be used with a debug monitor to single step the processor.

Branch Trace Event—Signalled each time a branch instruction is executed. For conditional branch instructions, this event is only signalled when the branch is taken. Branch-and-link, call, and return instructions do not signal this trace event.

Call Trace Event—Signalled each time a branch-and-link or call instruction is executed. Implicit calls, such as those used in interrupt or fault handling, signal this event. When a call trace event occurs, the prereturn trace flag (bit 3 in local register **r0**) is set by the processor to indicate a prereturn trace pending.

Pre-Return Trace Event—Signalled just prior to any **ret** instruction. This event is only signalled if the pre-return trace flag in register **r0** is set. Since the pre-return trace flag is set when a call trace event occurs, the call trace mode must be enabled before a pre-return trace event can be signalled.

Return Trace Event—Signalled each time a **ret** instruction is executed.

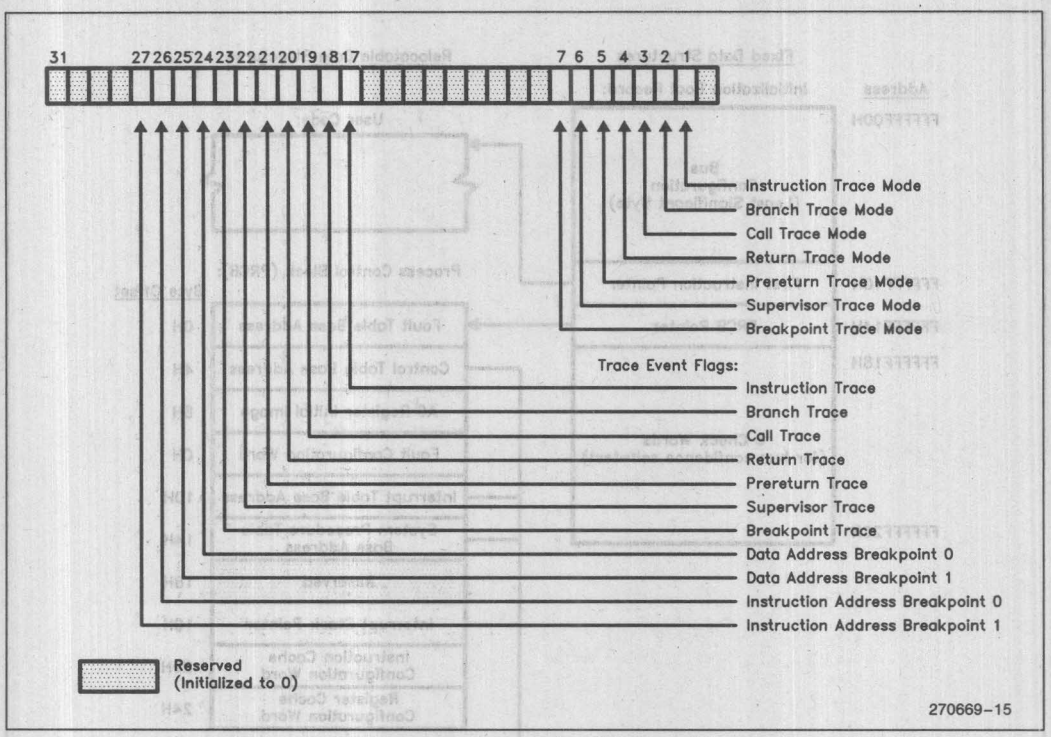


Figure 3-12. Trace Control Register

Supervisor Trace Event—Signalled each time a **calls** instruction is executed where the selected entry type is supervisor, or when a **ret** from supervisor mode is executed.

Breakpoint Trace Events—Signalled each time a **mark** instruction, **fmark** instruction, or specified address is encountered in the instruction stream. The **mark** instruction signals an event when the breakpoint trace mode is enabled, the **fmark** (force mark) instruction will generate a breakpoint trace event regardless of the value of the breakpoint trace mode bit.

Two IP breakpoint registers and two internal data address breakpoint registers are provided on the 80960CA. These breakpoints are loaded with an instruction or data address using the system control (**sysctl**) instruction. When the address is encountered and the breakpoint trace mode bit is set, a breakpoint trace event occurs. A corresponding instruction or data address event flag is set in the TC register when the address is encountered.

3.10.5 PROCESSOR INITIALIZATION

The Initial Memory Image (IMI) are the data structures needed to initialize the 80960CA (Figure 3-13). The initialization boot record, in reserved memory beginning at FFFFFF00H, contains a pointer to the Processor Control Block (PRCB). The PRCB in turn holds pointers to the data structures which are necessary to execute code on the 80960CA. The PRCB also holds several fields which contain information to initially configure the 80960CA.

Processor initialization begins by asserting the $\overline{\text{RESET}}$ pin. At initialization the processor optionally performs an internal self-test. A bus confidence test is also performed by calculating a checksum of 8 words read from external memory. If either of these self-tests fails, the $\overline{\text{FAIL}}$ pin indicates the failure and the processor aborts initialization. If the self-test passes, the 80960CA continues with initialization and branches to the first address of the user's code.

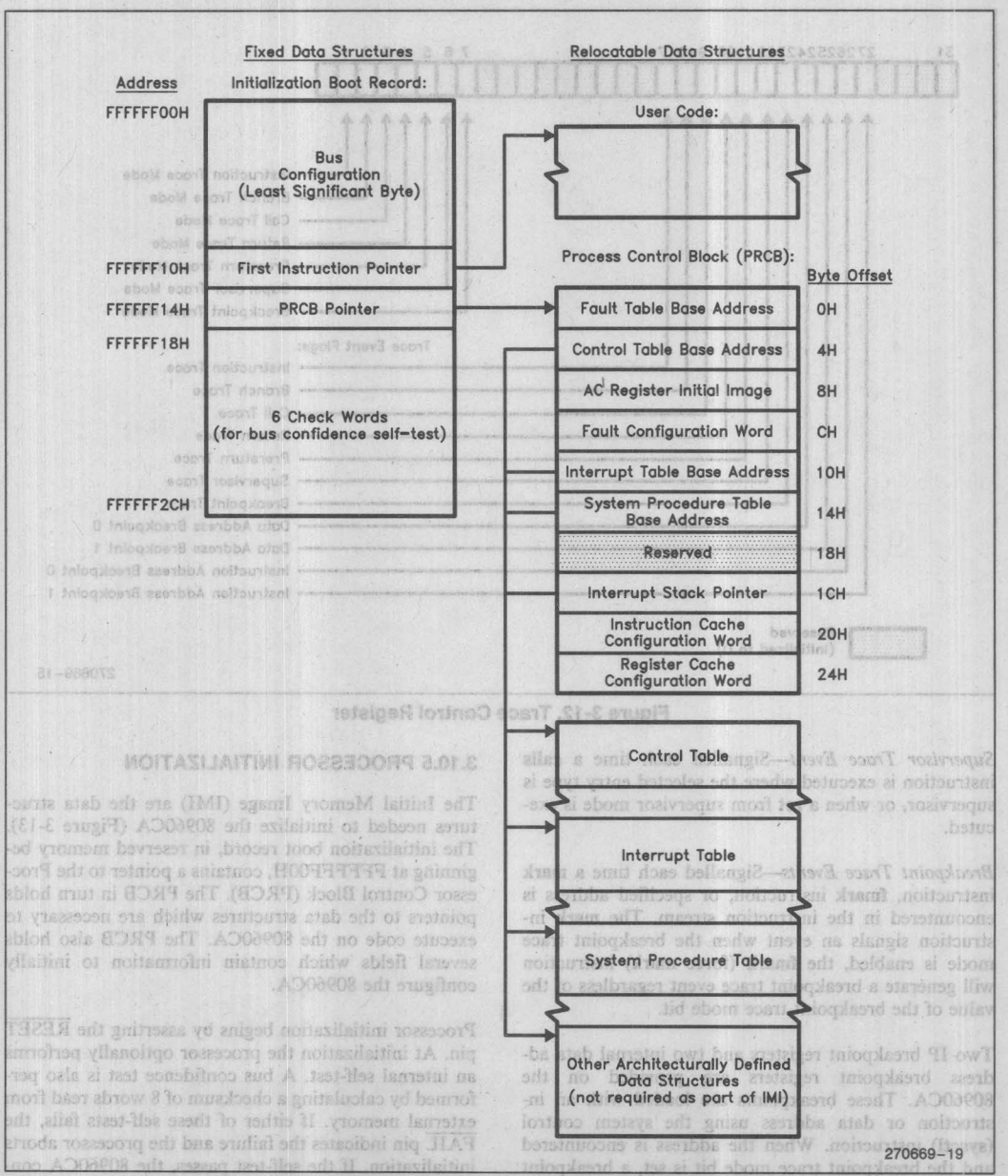


Figure 3-13. Initial Memory Image

4.0 80960CA SYSTEM IMPLEMENTATION

This section is an overview of the peripherals integrated with the 80960CA core. The features and operation of the Bus Controller, DMA Controller, Interrupt Controller, and the interfaces between these peripherals and the core are described.

4.1 Peripheral Interface

A program communicates with the on-chip peripherals by reading or modifying the special function registers (SFRs) or by loading control registers. The SFRs generally serve to transfer status information and data between a peripheral and the core, and the control registers serve to configure the peripherals. SFRs are accessed directly as instruction operands. The control registers are loaded by using the system control (**sysctl**) instruction.

4.2 Bus Controller Unit

The Bus Controller Unit (BCU) manages the data and instruction path between the 80960CA and external memory. Data operations and instruction fetches share a 32-bit data bus. Memory addresses are output on a separate 32-bit address bus. The BCU incorporates several advanced features to simplify the bus interface to external memory. A programmable *memory region configuration table* allows the characteristics of the external bus to be programmed differently for 16 separate regions in memory. The attributes of the external bus which are programmable include wait states and external ready control, data bus width (8, 16, or 32 bits), burst mode, address pipelining, and byte ordering. The region programmable bus options are described in this section.

4.2.1 BUS TRANSFERS, ACCESSES, AND REQUESTS

The distinction between *transfer, bus access,* and *bus request,* as these terms apply to the 80960CA, must be presented before beginning a discussion of the BCU.

Transfer—A *bus transfer* is defined simply as a movement of code or data between a memory system and the 80960CA. A write transfer occurs when the memory system is the destination of a data movement. A read transfer occurs when the 80960CA is the destination for a data or a code fetch from memory.

Bus Access—A *bus access* is defined as an address cycle and one or more transfers. In burst mode, an access can consist of a single address cycle and 1 to 4 transfers.

Bus Request—A *bus request* is issued by the core and directed to the Bus Controller. A bus request is sent to the BCU when a load, store, or an atomic instruction is executed, or when an instruction fetch is needed. Bus requests are also issued by the core to perform DMA transfers. A bus request can consist of one or more bus accesses. For example, an aligned word (32-bit) request to an 8-bit memory region will result in four byte-length accesses.

4.2.2 BUS CONTROL COPROCESSOR

The 80960CA's peripherals are often referred to as coprocessors, since their operation is decoupled from the execution of the instruction stream. As an integrated coprocessor, the BCU receives bus requests and independently carries out the action of moving data or code between the processor and external memory. The BCU uses a three deep queue to store pending bus requests. The queue decouples the core from the BCU, since a series of adjacent requests may be issued faster than the BCU can service each request. Two of the three queue entries store requests from a user's program (loads, stores, fetches, etc.). The third queue entry is used by requests originating from a DMA operation. This queue entry takes user requests when the DMA is turned off. The 80960CA alternates service of requests issued by the user program and requests issued by a DMA operation.

4.2.3 SIGNAL DESCRIPTIONS

The external bus signals consist of 30 address signals, 4 byte enables, 32 data lines, and various control signals.

D31–D0 32-bit Data Bus (bi-directional)—32-, 16-, and 8-bit values are transmitted and received on these lines. The 8- and 16-bit quantities are transferred on the low order data lines when a memory region is configured respectively for an 8- or 16-bit bus.

A31–A2 30-bit Address (outputs)—The 30-bit address bus identifies all external addresses to word (4-byte) boundaries. The byte enable lines indicate the selected byte in each word.

$\overline{BE3}$–$\overline{BE0}$ Byte Enables (outputs)—The byte enables select which of 4 addressed bytes are active in a memory access. When a memory region is configured for an 8-bit bus width, $\overline{BE1}$ and $\overline{BE0}$ act as the lower two bits of the address. For a 16-bit memory region, $\overline{BE1}$, $\overline{BE3}$, and $\overline{BE0}$ are encoded to provide A1, $\overline{BHE}$, and $\overline{BLE}$ respectively.

W/$\overline{R}$ Write or Read (output)—This signal is low for read accesses and high for write accesses.

$\overline{ADS}$ Address Strobe (output)—Indicates valid address and the start of a new bus access.

DT/$\overline{R}$ Data Transmit or Receive (output)—Direction control for data transceivers; similar to W/$\overline{R}$.

$\overline{DEN}$ Data Enable (output)—Low during a bus request after the first address cycle. This signal is used to control data transceivers and to indicate the end of a bus request.

$\overline{WAIT}$ Wait (output)—Indicates that wait states are being inserted by the internal wait state generator.

$\overline{READY}$ Ready (input)—Signals that data is valid for a read transfer or ends data hold for a write transfer. This function can be disabled for a memory region.

$\overline{BTERM}$ Burst Terminate (input)—Terminates a burst access. Another address is generated to complete the request when the signal is deasserted. This function can be disabled for a memory region.

D/$\overline{C}$ Data or Code (output)—Indicates a data transfer or a code fetch.

$\overline{DMA}$ DMA Access (output)—Indicates that a bus request was initiated by either the user program or the DMA.

$\overline{SUP}$ Supervisor Access (output)—Indicates that a bus access originated from a bus request issued in supervisor mode. This signal can be used to protect system data structures, or peripherals from errant modification by the user code.

$\overline{LOCK}$ Lock (output)—Indicates that an atomic memory operation is in progress. This signal can be used to inhibit external agents from modifying memory which is atomically accessed.

$\overline{BLAST}$ Burst Last (output)—Indicates the last transfer in a burst access.

HOLD Hold (input)—HOLD can be used by a bus requester to request access to the bus. The processor asserts HLDA after the current bus request or locked requests have completed.

HOLDA Hold Acknowledge (output)—Indicates to a bus requester that the processor has relinquished control of the bus.

BREQ Bus Request (output)—Indicates that requests are queued in the bus controller and are waiting to be serviced. BREQ can be used for external bus arbitration logic in conjunction with HOLD and HLDA to regain bus mastership.

Figure 4-1 shows the timing for a simple, non-burst, non-pipelined read and write access. The timing relations for the key control signals are shown in this figure.

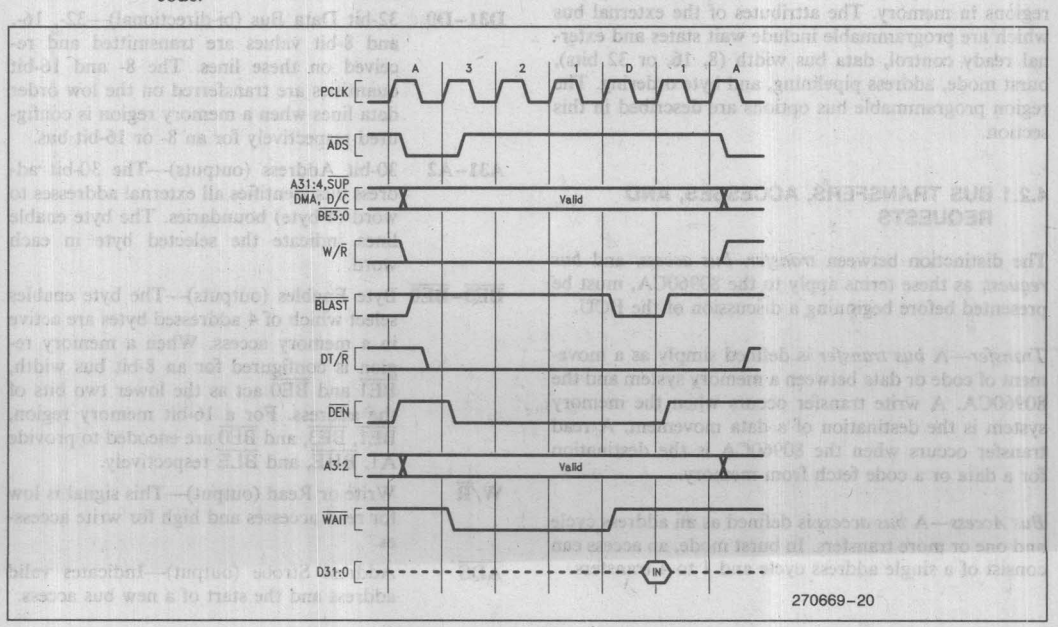


Figure 4-1. Basic Read and Write Request

4.2.4 MEMORY REGION CONFIGURATION TABLE

The BCU can be configured differently for 16 separate sections (referred to as regions) of the address space. The four most significant bits of a memory address define the location of each region in memory. The bus characteristics in a region are specified in the *memory region configuration table.* When a bus request is serviced, the BCU accesses the configuration table entry for the region addressed and services the request based on the bus characteristics programmed for that region. The characteristics programmed for each region are listed below:

- Burst Mode (on/off)
- Wait States (5 parameters)
- Bus Width (8-, 16-, or 32-bit)
- Ready Inputs (on/off)
- Address Pipelining (on/off)
- Byte Ordering (Big/Little Endian)

The flexibility of region programming simplifies the bus interface in applications where a memory system is made up of a variety of sub-systems, such as SRAM, DRAM, ROM, and memory mapped peripherals. Each memory sub-system can be mapped into a different region in memory, and that region can be configured specifically for the requirements of the particular memory sub-system.

The configuration table is made up of 16 on-chip control registers (Figure 4-2). Each register is programmed with the configuration information for a single region. Since the region table is located on-chip, access to region information does not affect the performance of the bus.

4.2.4.1 Burst Accesses

The 80960CA BCU is capable of burst accesses to memory systems which are designed to support this feature. Burst mode is intended to get the most performance from low cost memory systems. A burst access is a single address cycle followed by successive data or instruction transfers. The transfers reference data or instructions at sequential addresses starting at the address which began the burst access (Figure 4-3). In a burst memory system, the upper 28 bits of an address remain fixed while the lower two bits A2 and A3 increment to access subsequent locations.

Wait state timing for the first access of a burst request is controlled independently from the timing for subsequent accesses. A memory sub-system using static column mode or page mode DRAMs, for example, can take advantage of the short column access times for these devices by using burst mode. Interleaved ROM or EPROM systems can also be constructed which simultaneously access several words and then use burst mode to multiplex the multi-word array onto the data bus.

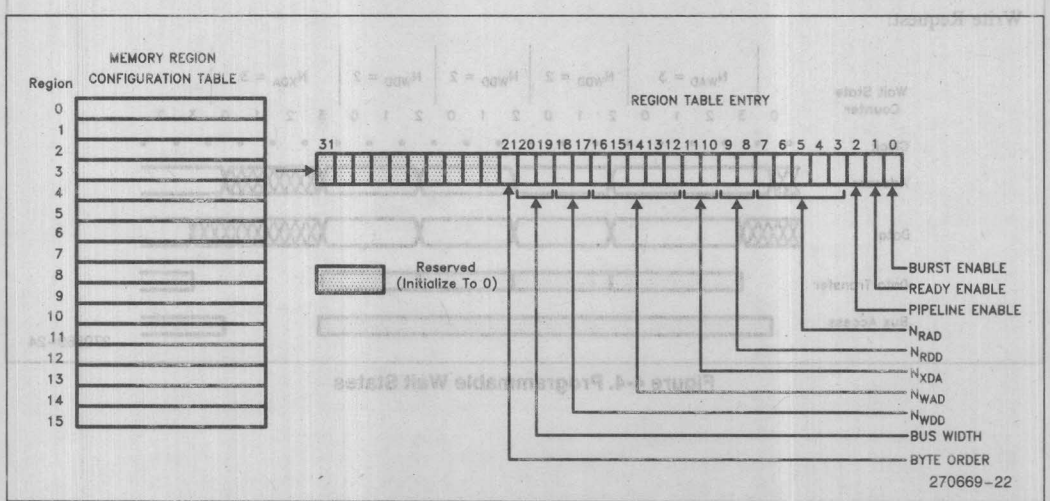


Figure 4-2. Memory Region Configuration Table

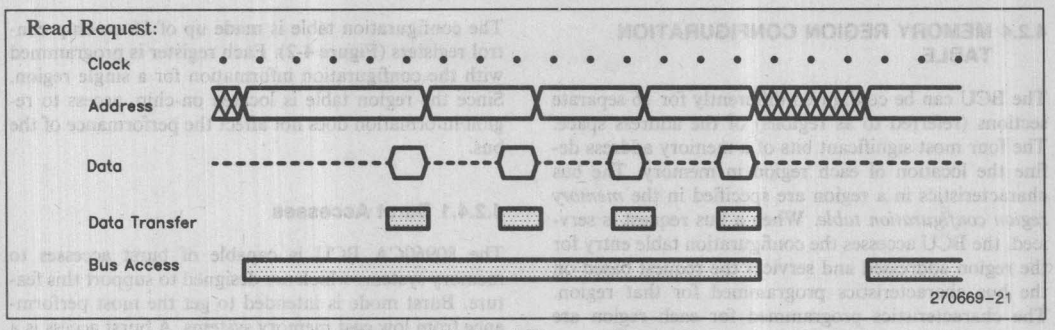


Figure 4-3. Burst Memory Request

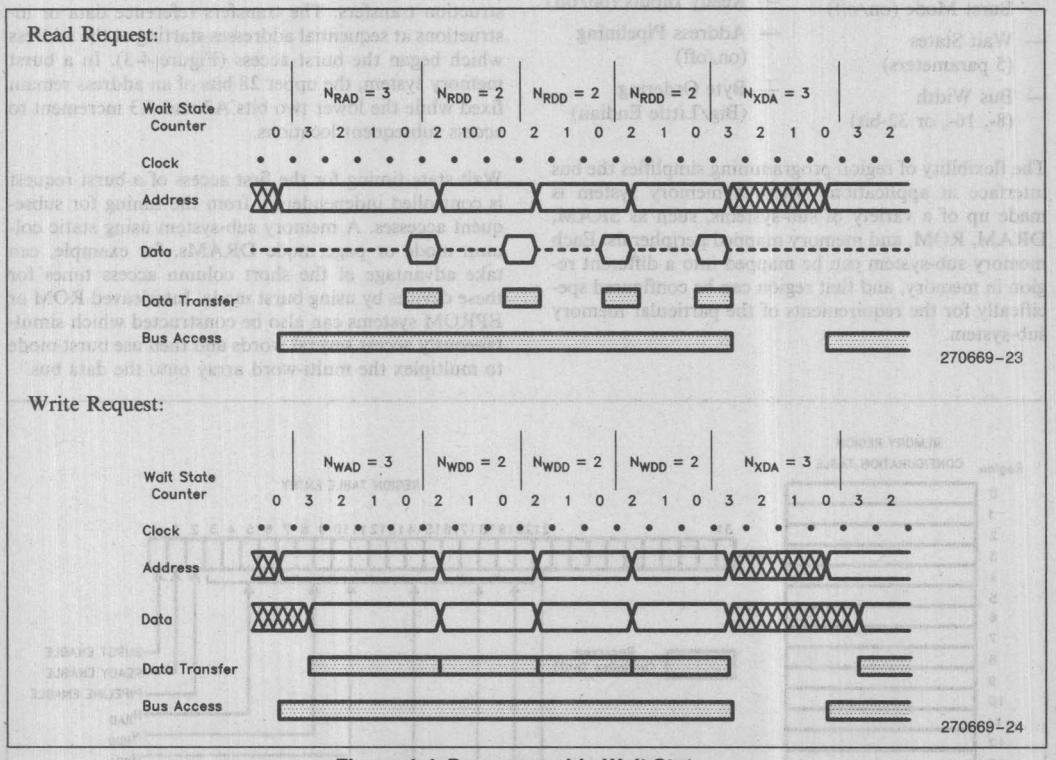


Figure 4-4. Programmable Wait States

4.2.4.2 Programmable Wait State Generation

The 80960CA may be interfaced with a variety of memory sub-systems and peripherals with a minimum system cost and complexity. To achieve this interface flexibility, the 80960CA implements an internal programmable wait state generator. Internally generated wait states eliminate the potential system delays which come from generating wait states with external logic.

Wait states are programmed for each region in the memory region configuration table. The number of wait states is programmable over a range which allows efficient control of memory devices ranging from ultra-fast SRAMs to slow peripherals. An external ready signal is also provided for external wait state control.

The wait states which can be generated by the 80960CA are shown in Figure 4-4. In this table N is the number of wait states inserted. The wait states for read accesses and for write accesses are described by three parameters each. For read accesses, N_{RAD} is the number of states between the address cycle and the first data cycle and N_{RDD} is the number of states between consecutive data cycles in a burst access. For writes, N_{WAD} is the number of states that data is held after an address cycle, and N_{WDD} is the number of states that data is held for consecutive data cycles in a burst write. For both reads and writes, N_{XDA} is the number of dead cycles after the last data cycle and before the next address.

4.2.4.3 READY Control

The memory region configuration table allows the ready input ($\overline{READY}$) to be enabled or disabled for each region. If the ready input is disabled, the external input has no effect on the wait states generated for a memory access; all wait states are generated internally. If the ready input is enabled, it works in conjunction with the programmable wait state generator. In this case, the ready input has no effect until the number of programmed wait states has expired. When the wait state counter reaches 0, the ready input is sampled, and wait states continue or are terminated based on the value of the ready input. In order to gain complete external control over wait states, all wait state parameters for a region can be set to 0.

4.2.4.4 Pipelined Reads

The 80960CA BCU provides an address pipelining mode (Figure 4-5) to optimize the performance of instruction and data fetches from external memory. When the pipelined read mode is enabled, an address cycle overlaps with the last data cycle in each access, effectively reducing the total time needed for each access. Pipelining mode is selected in each region by programming the memory region configuration table.

4.2.4.5 Byte Ordering

One of two configurations for byte ordering, often referred to as little endian or big endian, is selected for each region by programming the memory region configuration table. The byte ordering options make the 80960CA capable of sharing memory with a processor which uses either byte ordering scheme. Byte ordering refers to the way that the 80960CA relates internal data to the way that data is stored or fetched from memory. The little endian configuration orders the bytes in a short-word or word so that the least significant byte of the quantity is positioned at the lowest address and the most significant byte at the highest address in memory. Conversely, for the big endian configuration, the least significant byte is positioned at the highest address, and the most significant byte at the lowest address. For example, for little endian ordering, byte 0 for word data would be found in memory at an address of the form XXXX XXX0H and, for big endian, at address XXXX XXX3H.

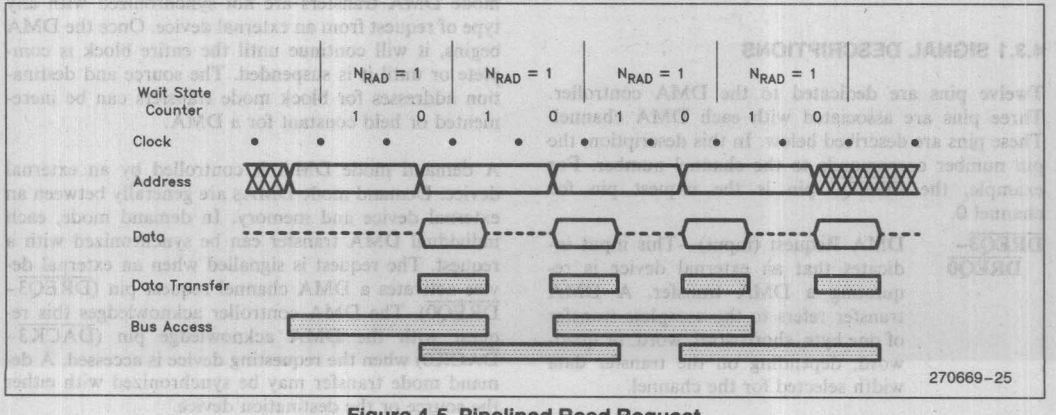


Figure 4-5. Pipelined Read Request

4.2.4.6 Data Alignment

The 80960CA can service any aligned or non-aligned bus request. Aligned requests are directed to their natural boundary in memory. In other words, the addresses for aligned requests are even multiples of the length of the data transferred. Non-aligned requests are not serviced directly by the BCU but are assisted by microcode. Microcode automatically breaks non-aligned requests into multiple aligned requests which are then reissued to the BCU. Depending on the degree of non-alignment and the length of the original request, the resulting requests by microcode will consist of a combination of byte, short-word, and double-word requests. The BCU is able to generate an operation-unaligned fault when a non-aligned bus request is first received. This fault can be selectively masked at initialization.

4.3 DMA Controller

The DMA controller is a high-performance, full-functioned integrated peripheral. The DMA controller can manage 4 channels of DMA transfer concurrent with program execution. Separate external control for each channel is provided. Each channel supports high-performance memory to memory transfers where the source and destination can be any combination of internal data RAM or external memory. The DMA Controller supports various types of transfers such as high-speed fly-by transfers and data chaining with the use of linked descriptor lists in memory.

The 80960CA's DMA controller is implemented using dedicated hardware and microcode. Because of the efficiency of the core, it is possible for the microcode to execute DMA transfers at high speeds. DMA transfers are performed by the core concurrently with execution of the user's program. Internal DMA logic is used for sampling requests, synchronizing transfers with external devices, and handling the service of multiple active channels.

4.3.1 SIGNAL DESCRIPTIONS

Twelve pins are dedicated to the DMA controller. Three pins are associated with each DMA channel. These pins are described below. In this description, the pin number corresponds to the channel number. For example, the $\overline{\text{DREQ0}}$ pin is the request pin for channel 0.

$\overline{\text{DREQ3}}$–$\overline{\text{DREQ0}}$ DMA Request (input)—This input indicates that an external device is requesting a DMA transfer. A DMA transfer refers to the complete transfer of one byte, short-word, word, or quad-word, depending on the transfer data width selected for the channel.

$\overline{\text{DACK3}}$–$\overline{\text{DACK0}}$ DMA Acknowledge (output)—This output becomes active when the requesting device is accessed.

$\overline{\text{EOP3/TC3}}$–$\overline{\text{EOP0/TC0}}$ End of Process (input) or Terminal Count (output)—This pin functions either as an input ($\overline{\text{EOPx}}$) or as an output ($\overline{\text{TCx}}$). When programmed as an output, the pin is driven active for one clock after byte count reaches zero and a DMA terminates. When programmed as an input, an external device can cause the DMA operation to terminate.

4.3.2 DMA TRANSFERS

The 80960CA DMA controller supports a variety of transfer modes and variations of these modes, allowing the DMA to adapt to a number of hardware systems and the performance requirements of these systems.

4.3.2.1 Standard Block and Demand Mode Transfers

A standard DMA transfer is made up of multiple bus requests. Loads from a source address are followed by stores to a destination address. The DMA controller issues the proper combination of these bus requests to execute the DMA transfer. For example, a typical DMA transfer between memory and an 8-bit peripheral could appear as a single byte load request directed to the source memory, followed by a single byte store request directed to the 8-bit peripheral.

The DMA controller has two basic transfer modes: block mode (unsynchronized) and demand mode (synchronized). Any DMA transfer will be serviced by one of these basic transfer modes.

A block mode DMA is initiated by software. Block mode DMAs are generally between memory. Block mode DMA transfers are not synchronized with any type of request from an external device. Once the DMA begins, it will continue until the entire block is complete or until it is suspended. The source and destination addresses for block mode transfers can be incremented or held constant for a DMA.

A demand mode DMA is controlled by an external device. Demand mode DMAs are generally between an external device and memory. In demand mode, each individual DMA transfer can be synchronized with a request. The request is signalled when an external device activates a DMA channel request pin ($\overline{\text{DREQ3}}$–$\overline{\text{DREQ0}}$). The DMA controller acknowledges this request with the DMA acknowledge pin ($\overline{\text{DACK3}}$–$\overline{\text{DACK0}}$) when the requesting device is accessed. A demand mode transfer may be synchronized with either the source or the destination device.

4.3.2.2 Fly-by Transfers

A fly-by transfer mode is provided for the most performance-critical DMA applications. Fly-by mode also makes very efficient use of the external bus during a DMA. Standard DMA transfers involve multiple bus requests: load requests directed to the source and a store request directed to the destination. Fly-by transfers only require a single bus request. For a fly-by transfer, memory sees a load or a store on the bus while the requesting device is selected by the DMA acknowledge pin. The data is never actually read from or written to the 80960CA. For memory to device transfers, the processor issues a load, and, while reading the memory, accesses the external device with the DMA acknowledge pin. The data is then written directly to the destination device with a single bus request. For a device to memory transfer, the reverse operation is performed. The DMA issues a store, and, while writing the memory, accesses the source device with the DMA acknowledge pin. In this case, the processor floats the data bus and the device's data is written directly into memory.

4.3.2.3 Data Chaining

Each DMA channel can be programmed in a data chaining mode. In this mode, all transfer information is taken from a linked-list descriptor in memory (Figure 4-6). Data chaining is started by specifying a pointer to a descriptor in memory. The transfer continues until the number of bytes in the byte count field in the descriptor is transferred. At this time, another linked-list descriptor may be executed. The next descriptor is specified by the next-pointer field in the current description. Data chaining continues until a null pointer is encountered in the next-pointer field. Data chaining can be designated as source chaining, destination chaining, or both.

In data chaining mode, an option exists which allows chaining descriptors to be updated while the DMA is running. When this option is enabled, the DMA sets a bit in the DMA's special function register after loading a descriptor and then checks this bit before loading the next descriptor. If the bit has been cleared by the user, the DMA continues; otherwise, the DMA waits for the next descriptor to be set up and for the user to clear the bit. An interrupt can be generated when each buffer is complete or when the DMA is terminated with a null pointer or the EOP pin.

4.3.3 TRANSFER CHARACTERISTICS

The DMA controller provides the programmer with a number of options for configuring the characteristics of a DMA transfer. Intelligent selection of transfer characteristics works to balance DMA performance and functionality with performance of the user program when the DMA is in progress.

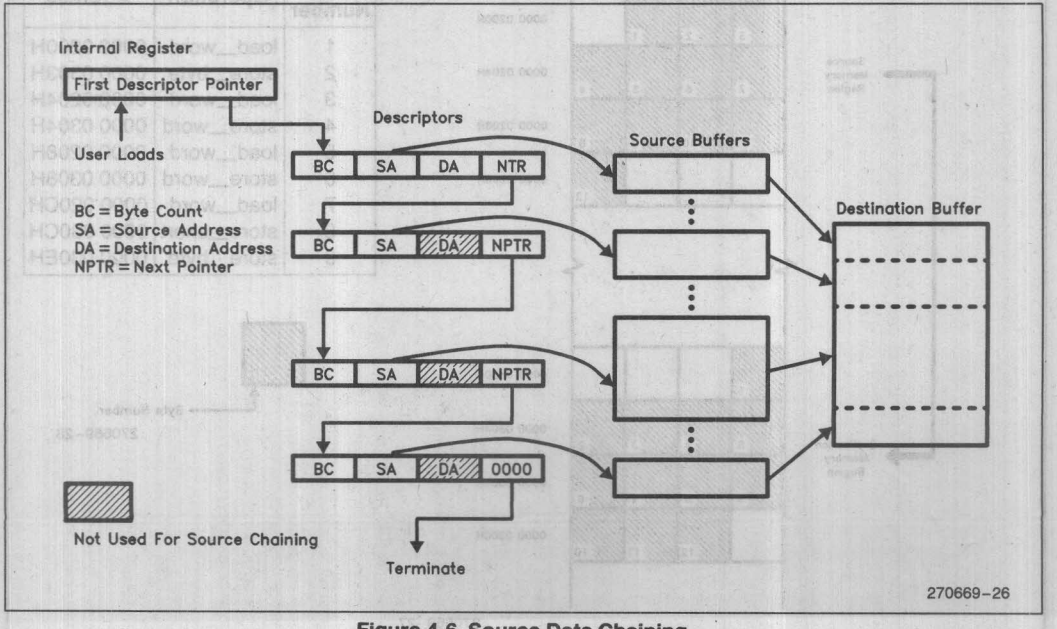


Figure 4-6. Source Data Chaining

The DMA controller provides features to optimize transfers by moving a maximum amount of data for each bus request issued. This is controlled by specifying the width of the source and destination directed bus requests for a DMA transfer, and by on-chip assembly or disassembly of the transfer when source and destination are not of equal widths.

Data alignment is performed automatically by the DMA controller when the source and destination of a transfer are not aligned. The alignment algorithm is optimized for many transfers, providing a performance comparable to the aligned transfer cases.

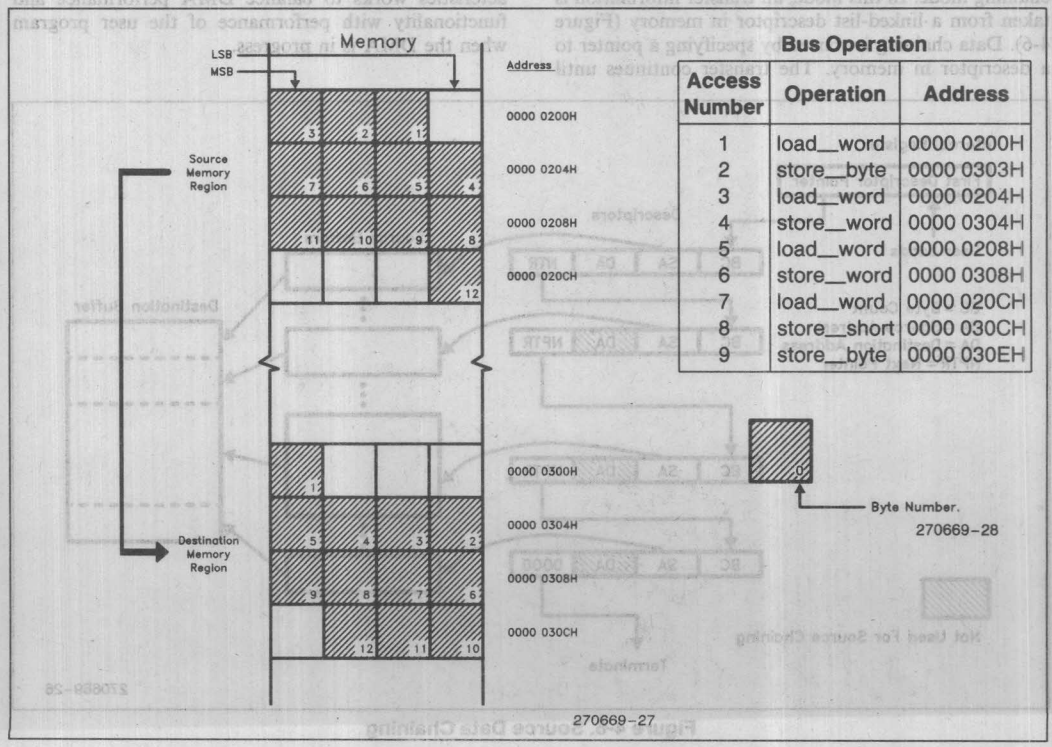
4.3.3.1 Transfer Data Length

The transfer data length specifies the length of bus requests directed to the source and destination in a standard DMA transfer. Byte, short, word, or quad-word loads and stores are selected for either source or destination when a DMA channel is set up. Assembly and disassembly of data is automatically performed when the source and destination widths are different. This feature provides the most efficient use of the bus when DMA transfers occur between a source and a destination with different external bus widths.

The DMA controller provides the option of using quad word transfers to enhance DMA performance. When quad transfers are specified, the DMA will request a four-word load request and four-word store request for each DMA transfer. The trade-off for the added DMA performance is latency on the external bus, preventing requests by the core, or by another DMA channel from being immediately serviced.

4.3.3.2 Data Alignment

The DMA controller supports transfer of source and destination data aligned to different byte boundaries in memory. The DMA implements microcode algorithms to transfer some non-aligned data with a performance level approaching that for aligned transfers. The DMA accomplishes this by attempting to issue the maximum number of aligned bus requests during a DMA (Figure 4-7). As shown, most of the overhead due to non-aligned DMAs is incurred at the beginning and end of the DMA. DMAs with low byte counts, therefore, do not benefit as much from the data alignment features of the DMA. The alignment feature is optimized for 8-bit to 8-bit, 32-bit to 32-bit and for 8-bit and 32-bit combinations of source and destination lengths.



Bus Operation

Access Number	Operation	Address
1	load_word	0000 0200H
2	store_byte	0000 0303H
3	load_word	0000 0204H
4	store_word	0000 0304H
5	load_word	0000 0208H
6	store_word	0000 0308H
7	load_word	0000 020CH
8	store_short	0000 030CH
9	store_byte	0000 030EH

Figure 4-7. DMA Data Alignment

4.3.3.3 Channel Priority

The DMA controller arbitrates the priority of the 4 DMA channels. If multiple DMA channels are enabled, the DMA controller will determine in which order each channel is serviced.

The DMA controller can be configured in one of two priority modes, fixed mode or rotating mode. The fixed mode assumes a fixed priority for each channel with channel 0 having the highest priority, followed by channels 1, 2, and 3, with channel 3 having the lowest priority. The rotating mode updates a channel's priority to the lowest priority after that channel's DMA is made. This insures that a single channel is never locked out by other active channels. The priority sequence is always in the same order, with priority rotating from the low channel numbers to the high channel numbers.

4.3.3.4 Performance and Latency Considerations

DMA operations and the user program share the resources of the core and of the external bus. DMA performance and the performance of the user program are coupled directly to the balance of load sharing between these two processes. The core resources necessary to perform a DMA transfer vary depending on the way a channel has been configured. For example, byte assembly and disassembly requires more processor overhead per byte of transfer than does a transfer in which the source and destination transfer lengths are equal. The performance of a DMA is also tightly coupled to the user program's use of the external bus. If the user program does not make frequent bus requests, the requests by the DMA controller will be serviced with little or no delay.

The user can enhance performance of the DMA with trade-offs in system complexity and flexibility. Aligned transfers eliminate the microcode overhead needed to perform the internal alignments. DMAs between regions of equal transfer widths eliminate overhead for assembly and disassembly. Source or destination memory configured as burst memory will provide the most efficient use of the DMA controller when the quad-transfer feature is enabled. Using the fly-by mode reduces the number of bus requests needed for a DMA since fly-by mode uses only a single load or a single store request for each transfer.

4.3.4 DMA CONTROL AND CONFIGURATION

The DMA Controller uses an SFR register, the DMA command (DMAC) register, and the setup DMA (**sdma**) instruction for configuration and control of a DMA. The **sdma** instruction is used to configure each DMA channel. Transfer widths, byte count, source and destination addresses for a DMA are specified in this instruction.

The DMAC register (Figure 4-8) is described below.

The *channel enable field* enables a DMA once the channel is set up. Clearing these bits will also cause a DMA transfer to be suspended.

The *terminal count field* signals that byte count has reached zero and a DMA has ended.

The *channel active field* indicates that a channel is idle or active. If set, this bit indicates that the channel is active. This implies that the channel is servicing a transfer or has a request pending. The active bits are status information only.

The *channel done field* indicates that a DMA operation is complete. The done bits are status information only.

The *channel wait field* is used for handshaking with a user program in data chaining mode. The DMA sets these bits when a new linked-list descriptor is read. The DMA will not read the next descriptor until this bit is cleared by the user. The user can set up the next descriptor and then clear the channel wait bits to dynamically change descriptors.

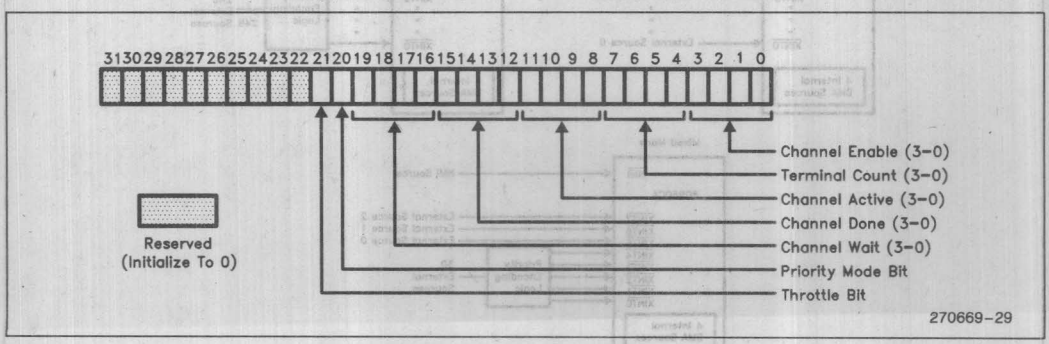


Figure 4-8. DMA Command Register

A *priority mode bit* selects rotating or fixed priority mode.

The *throttle bit* selects the maximum amount of core resources that the DMA microcode will receive in relation to the execution of the user program.

4.3.5 DMA INTERRUPTS

The DMA controller is the source of 4 hardware interrupts in the 80960CA. The DMA Controller can be programmed to request an interrupt when a DMA is complete, or when a buffer transfer is completed in chaining mode. Each channel requests a different interrupt.

4.4 Interrupt Controller

The 80960CA *Interrupt Controller* manages interrupts which are requested by external agents or by the DMA Controller. The interrupt controller manages 4 internal DMA interrupt sources, a single NMI (Non-Maskable Interrupt) pin, and 8 external interrupt pins. Up to 248 external interrupt sources can be supported by the interrupt controller. The interrupt controller handles the prioritization of software interrupts, hardware interrupts, and the process priority, and signals the core when interrupts are to be serviced. The interrupt controller provides the low-latency interrupt service featured on the 80960CA.

4.4.1 EXTERNAL INTERRUPTS

The 80960CA provides 8 interrupt pins and one NMI pin for detecting external requests. The interrupt controller allows the 8 interrupt pins to be configured as dedicated inputs capable of requesting 8 interrupts, or as a vectored input capable of requesting up to 248 interrupts. The NMI pin is always a dedicated input. The interrupt controller pins are described below.

$\overline{\text{XINT7}}$–$\overline{\text{XINT0}}$ External Interrupts (inputs)—These pins can be used as dedicated inputs, or acting together as an 8-bit number, request any interrupt. The inputs are edge or level detected, and are optionally debounced internally.

$\overline{\text{NMI}}$ Non-Maskable Interrupt (input)—NMI requests the highest priority interrupt. NMI is always taken and is not maskable (as the name implies), and not interruptable.

4.4.2 INTERRUPT MODES

The 8 external interrupt pins can be configured in one of three modes: dedicated mode, expanded mode, or mixed mode (Figure 4-9).

4.4.2.1 Dedicated Mode Interrupts

In dedicated mode, each of the 8 interrupt pins acts as a dedicated input. When an external event is detected on an interrupt pin, a unique interrupt is requested for that pin. It is possible to map each dedicated pin to one of a number of possible interrupt vectors. This is accomplished by programming the interrupt map (IMAP) control registers with an interrupt vector number for each pin. (Recall that interrupt vector numbers are 8-bit values which reference the 248 vectors in the interrupt table.)

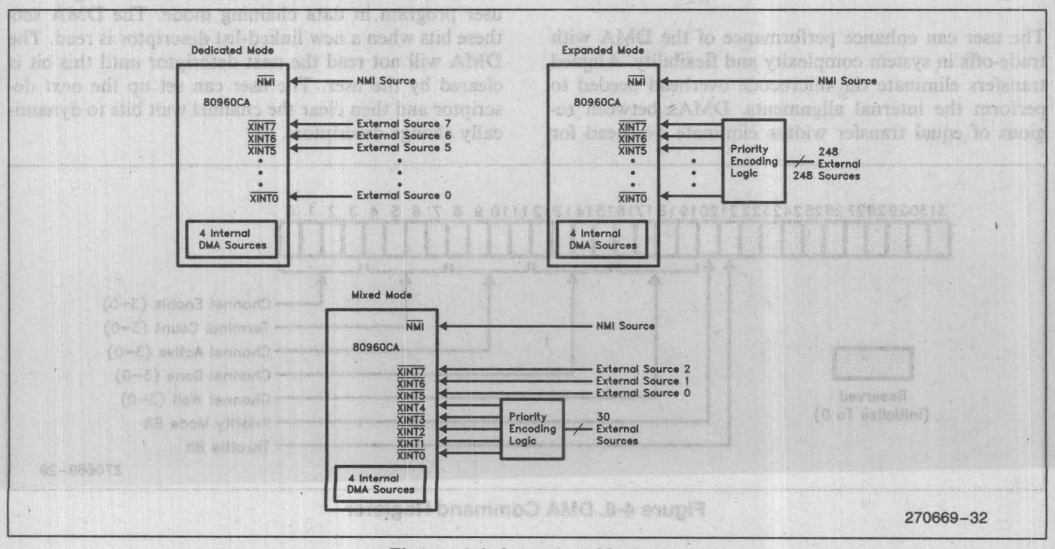


Figure 4-9. Interrupt Modes

Only the upper four bits of the vector number can be programmed for a dedicated mode interrupt. The lower four bits are fixed at the value 0010_2. With four programmable bits, one of 15 interrupt vectors is available for each dedicated pin. These interrupt vectors span the even priority levels from priority 2 to 30. The vector at priority 0 is not defined.

The 15 interrupt vectors available to dedicated sources can be cached in internal data RAM. If this interrupt vector caching feature is selected, the processor will automatically fetch the vector from data RAM, eliminating the latency caused by a bus request for a vector in external memory.

The DMA Controller can request four interrupts to signal the end of a DMA for each of four channels. The four interrupt signals from the DMA are handled by the interrupt controller in the same way as an interrupt pin configured as a dedicated input. Each of the four DMA sources may request one of 15 interrupts by programming the IMAP for that source.

4.4.2.2 Expanded Mode Interrupts

In expanded mode, external hardware considers the interrupt pins ($\overline{XINT0}$–$\overline{XINT7}$) as an 8-bit binary number. This number is used directly as the interrupt vector number. Each of the 248 possible interrupt vectors can be referenced in this way, allowing a separate external source for each vector. External hardware is responsible for recognizing individual hardware sources and then driving the interrupt vector number corresponding to that source onto the interrupt pins.

4.4.2.3 Mixed Mode Interrupts

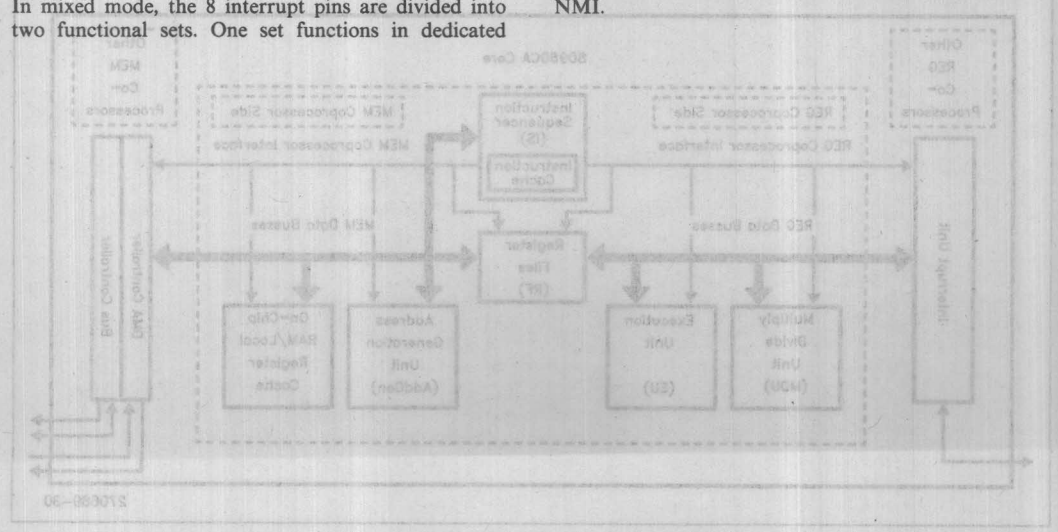
In mixed mode, the 8 interrupt pins are divided into two functional sets. One set functions in dedicated mode, the other in expanded mode. In mixed mode, three pins are dedicated interrupt pins ($\overline{XINT7}$–$\overline{XINT5}$). A programmable vector number is associated with each of these pins. The remaining five interrupt pins ($\overline{XINT4}$–$\overline{XINT0}$) are treated as the most significant five bits of the expanded mode vector number. The lower order bits are internally forced to 010_2 to form the full 8-bit value for the vector number.

4.4.3 INTERRUPT CONTROLLER SETUP

The interrupt controller uses two special function registers to manage interrupt requests by hardware sources. The hardware interrupt pending register (IPND) and the hardware interrupt mask register (IMSK) are addressed as sf0 and sf1 respectively. A single bit in each register corresponds to each of the 8 possible external sources and 4 DMA sources for hardware interrupts. The IMSK register performs the function of masking hardware interrupts and the IPND register implements posting of interrupts requested by hardware. When configured for expanded or mixed mode interrupts, bit 0 of the IMSK register globally masks the expanded mode interrupts.

4.4.4. NON-MASKABLE INTERRUPT

In addition to the maskable hardware interrupts, a single *Non-Maskable Interrupt (NMI)* is provided. A dedicated NMI pin is used to request this interrupt. NMI is defined as a higher priority than any hardware interrupt, software interrupt, or process priority. The NMI procedure, therefore, can never be interrupted and must execute the return instruction before other procedures can execute. The NMI procedure is entered through vector 248. This vector is cached in internal data RAM at initialization to reduce latency for the NMI.



APPENDIX A
80960CA CORE IMPLEMENTATION

The 80960CA Core is a high-performance implementation of the 80960 Core Architecture. This section briefly describes the microarchitecture of the 80960CA core and the key constructs used to achieve parallel instruction execution.

The 80960CA core can be divided into the 6 main subunits listed below.

— Instruction Sequencer
— Register File
— Execution Unit
— Multiply and Divide Unit
— Address Generation Unit
— Static Data RAM and Local Register Cache

Figure A-1 is a simple block diagram of the 80960CA. The nucleus of the processor is the Instruction Sequencer and Register File. The other subunits of the core, referred to as coprocessors, radiate from these units, connecting to either the register (REG) side or the memory (MEM) side of the processor. The Instruction Sequencer issues directives, via the REG and MEM interfaces, which target a specific coprocessor. That coprocessor then executes an express function virtually decoupled from the IS and the other coprocessors. The REG and MEM data busses shown in Figure A-1 are used to transfer data between the common Register File and the coprocessors.

A.1 Instruction Sequencer

The *Instruction Sequencer (IS)* decodes the instruction stream and drives the decoded instruction stream onto the coprocessor interfaces. In a single clock, the IS decodes up to 4 instruction and issues up to three of these instructions to the on-chip coprocessors or to the IS itself. One register (REG) format, one memory (MEM) format, and one control or control and branch (CTRL or COBR) format instruction can be issued at one time. These instructions are directed respectively to the REG coprocessors, the MEM coprocessors, or to the IS. The ability to issue multiple instructions in parallel can result in the simultaneous execution of many instructions at once. An optimizing compiler or hand optimization of assembly code can easily produce an instruction stream which takes full advantage of the parallel execution of the core.

A technique known as *resource scoreboarding* is used to manage the parallel execution of instructions and the common resources of the processor. A coprocessor, for example, can scoreboard itself, indicating that it cannot

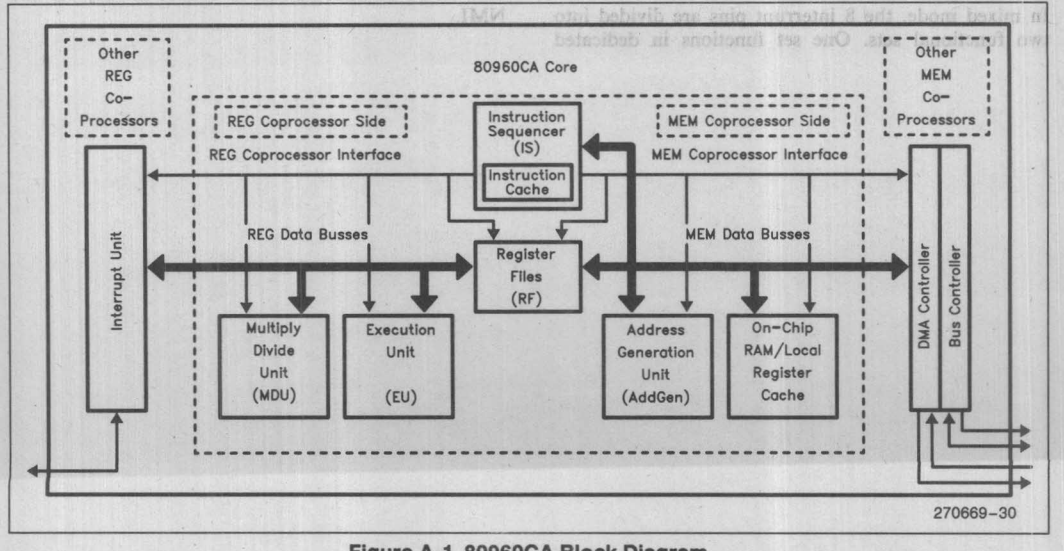


Figure A-1. 80960CA Block Diagram

act on another instruction until an instruction currently executing on that coprocessor is completed. A specific form of resource scoreboarding is referred to as *register scoreboarding*. When the computation stage of an instruction takes more than one clock, the destination register or registers for the result are scoreboarded as busy. A subsequent operation needing that particular register will be delayed until the multi-clock operation is completed. Instructions which do not use the scoreboarded registers can be executed in parallel.

The IS manages a three stage parallel instruction pipeline (Figure A-2). In the first stage of the pipeline (pipe 0), the address of the next instruction is calculated. This address may be the next sequential instruction, the target of a branch, or a location in microcode. In the second stage of the pipeline (pipe 1), the instructions are issued to the rest of the machine. In the third stage (pipe 2), the instruction computation is started, and for single cycle instructions, a result is returned.

Several microarchitectural features of the core are designed to minimize performance loss due to pipeline breaks.

Branch Prediction—To minimize pipeline breaks due to branching, the user can specify the direction that a conditional branch instruction will usually follow. The processor will execute along the specified instruction path with no pipeline break. If the branch direction specified was the direction actually selected by execution of the conditional branch, no pipeline break occurs. The direction of the branch guess is determined by a bit value in the CTRL format instructions.

Register Bypassing—Register bypassing is a feature which forwards the result of an instruction for immediate use as the source of another instruction. This forwarding occurs at the same time that the value is written to its destination register. Bypassing the register file saves the one clock cycle break which would otherwise occur while waiting for the value to be written to the register file and the register scoreboard to be cleared.

On-chip Cache—The on-chip instruction cache and local register cache eliminate many pipeline breaks which will occur if the IS is forced to wait for code or data to be moved between the 80960CA and external memory.

Register File Access—The Register File allows multiple instructions to gain access to the register set simultaneously. This eliminates pipeline breaks which would be caused by a loss of access to the register set by any coprocessor.

A.1.1 INSTRUCTION CACHE

The IS includes a 1 Kbyte two-way set associative instruction cache capable of delivering up to four instructions each clock to the Instruction Sequencer. The cache allows inner loops of code to execute with no external instruction fetches.

A.1.2 MICROCODE ROM

The 80960CA uses *microcode ROM* to implement complex instructions and functions. This includes calls, returns, DMA transfers, and initialization sequences. Microcode provides an inexpensive and simple method for implementing complex instructions in the mostly RISC environment of the 80960CA. When the IS encounters a microcoded instruction, it automatically branches to the microcode routine. The 80960CA performs this microcode branch in 0 clocks.

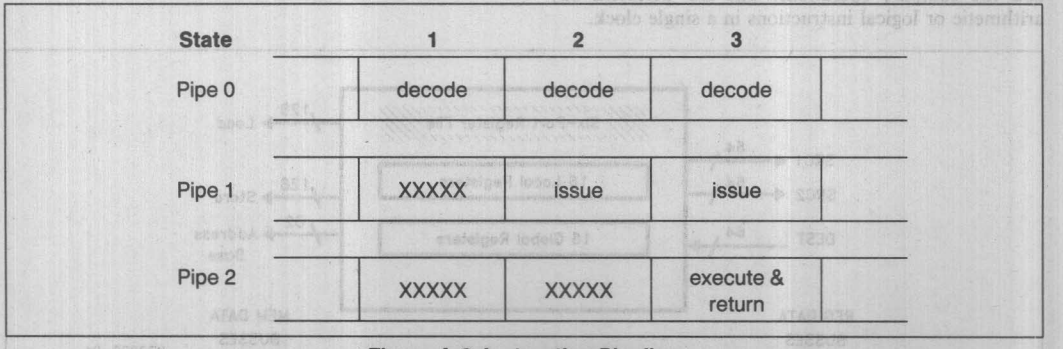


Figure A-2. Instruction Pipeline

A.2 Register File

The *Register File (RF)* contains the 16 local and 16 global registers. The register file has six ports (Figure A-3), allowing parallel access of the register set by several 80960CA coprocessors. This parallel access results in an ability to execute one simple logic or arithmetic instruction, one memory operation (load/store), and one address calculation per clock.

MEM coprocessors interface to the RF with a 128-bit wide load bus and a 128-bit wide store bus. These busses enable movement of up to 4 words per clock to and from the RF. These busses also allow LOAD data from a previous read access and STORE data from a current write access to be processed in the register file simultaneously. An additional 32-bit port allows an address or address reduction operand to be simultaneously fetched by the Address Generation Unit.

REG coprocessors interface to the RF with two 64-bit source busses and a single 64-bit destination bus. With this bus structure, two source operands are simultaneously issued to a REG coprocessor when an instruction is issued. A 64-bit destination bus allows the result from the previous operation to be written to the RF at the same time that the current operation's source operands are issued.

A.3 Execution Unit

The Execution Unit is the 32-bit Arithmetic and Logic Unit of the 80960CA Core. The EU can be viewed as a self-contained REG coprocessor with its own instruction set. As such, the EU is responsible for executing or supporting the execution of all the integer and ordinal arithmetic instructions, the logic and shift instructions, the move instructions, the bit and bit field instructions, and the compare operations. The EU performs any arithmetic or logical instructions in a single clock.

A.4 Multiply Divide Unit

The *Multiply and Divide Unit (MDU)* is a REG coprocessor which performs integer and ordinal multiply, divide, remainder, and modulo operations. The MDU detects integer overflow and divide by zero errors. The MDU is optimized for multiplication, performing 32-bit multiplies in 4 clocks. The MDU performs multiplies and divides in parallel with the main execution unit.

A.5 Address Generation Unit

The *Address Generation Unit (AGU)* is a MEM coprocessor which computes the effective addresses for memory operations. It directly executes the load address instruction (**lda**) and calculates addresses for loads and stores based on the addressing mode specified in these instructions. The address calculations are performed in parallel with the main execution unit (EU).

A.6 Data RAM and Local Register Cache

The *Data RAM and Local Register Cache* is part of a 1.5 Kbyte block of on-chip Static RAM (SRAM). 1 Kbyte of this SRAM is mapped into the 80960CA's address space from location 00000000H to 000003FFH. A portion of the remaining 512 bytes is dedicated to the Local Register Cache. This part of internal SRAM is not directly visible to the user. Loads and Stores, including quad-word accesses, to the internal SRAM are typically performed in only one clock. The complete local register set, therefore, can be moved to the local register cache in only four clocks.

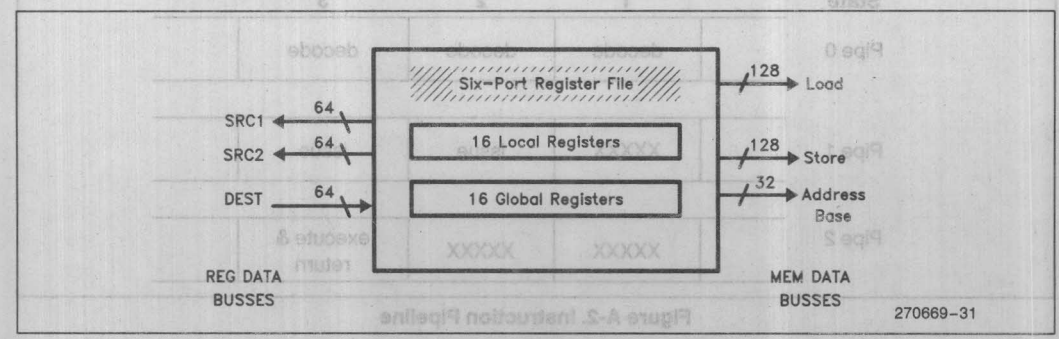


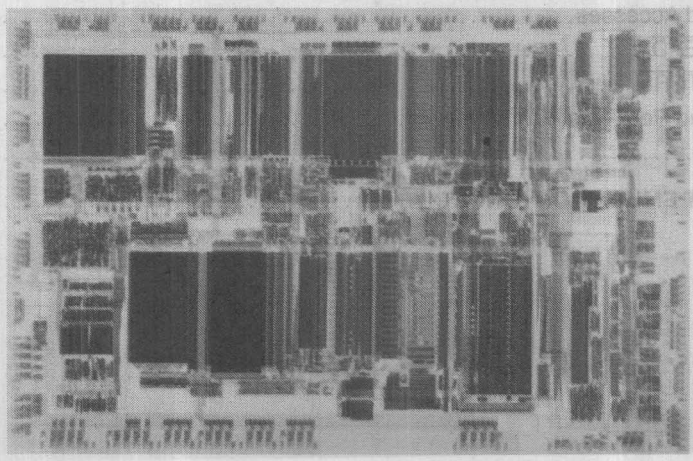
Figure A-3. Six-Port Register File

80960CA-40*, -33, -25, -16
32-BIT HIGH PERFORMANCE EMBEDDED PROCESSOR

- Two Instructions/clock sustained execution
- Four 59 Mbytes/s DMA Channels with Data Chaining
- Demultiplexed 32-Bit Burst Bus with Pipelining

- 32-bit Parallel Architecture
  - Two Instructions/clock Execution
  - Load/Store Architecture
  - 16, 32-bit Global Registers
  - 16, 32-bit Local Registers
  - Manipulate 64-Bit Bit Fields
  - 11 Addressing Modes
  - Full Parallel Fault Model
  - Supervisor Protection Model
- Fast Procedure Call/Return Model
  - Full Procedure Call in 4 clocks
  - RISC Call in 2 clocks (BAL)
- On-Chip Register Cache
  - Caches Registers on Call/Ret
  - Minimum of 6 Frames provided
  - Number of Frames Programmable, up to 15
- On-Chip Instruction Cache
  - 1 Kbyte Two-Way Set Associative
  - 128-bit Path to Instruction Sequencer
  - Cache-Lock Modes
  - Cache-Off Mode
- High Bandwidth On-Chip Data Ram
  - 1 Kbytes On-chip RAM for Data
  - Sustain 128-bits per clock access
- Four On-Chip DMA Channels
  - 59 Mbytes/s Fly-by Transfers
  - 32 Mbytes/s Two-Cycle Transfers
  - Data Chaining
  - Data Packing/Unpacking
  - Programmable Priority Method
- 32-Bit Demultiplexed Burst Bus
  - 128-Bit Internal Data Paths to *and* from Registers
  - Burst Bus for DRAM Interfacing
  - Address Pipelining Option
  - Fully Programmable Wait States
  - Supports 8, 16 or 32-bit Bus Widths
  - Supports Unaligned Accesses
  - Supervisor Protection Pin
- High-Speed Interrupt Controller
  - Up to 248 External Interrupts
  - 32 Fully Programmable Priorities
  - Multi-mode 8-bit Interrupt Port
  - Four Internal DMA Interrupts
  - Separate, Non-maskable Interrupt Pin
  - Context Switch in 750 ns Typical

*Samples available 4th quarter 1991.



270727-1

Figure 1. 80960CA Die Photo

December 1990
Order Number: 270727-003

CONTENTS

PAGE

1.0 PURPOSE 4-41

2.0 80960CA OVERVIEW 4-41
- 2.1 The C-Series Core 4-42
- 2.2 Pipelined, Burst Bus 4-42
- 2.3 Flexible DMA Controller 4-42
- 2.4 Priority Interrupt Controller 4-42
- 2.5 Instruction Set Summary 4-43

3.0 PACKAGE INFORMATION 4-44
- 3.1 Package Introduction 4-44
- 3.2 Pin Descriptions 4-44
- 3.3 80960CA Pinout 4-50
- 3.4 Mechanical Data 4-57
- 3.5 Package Thermal Specifications 4-61

4.0 ELECTRICAL SPECIFICATIONS 4-63
- 4.1 Absolute Maximum Ratings 4-63
- 4.2 Operating Conditions 4-63
- 4.3 Recommended Connections 4-63
- 4.4 D.C. Specifications 4-64
- 4.5 A.C. Specifications 4-65

5.0 RESET AND HOLD ACKNOWLEDGE 4-78

6.0 BUS WAVEFORMS 4-82
- 6.1 Basic READ/WRITE Accesses 4-82
- 6.2 Burst Accesses 4-85
- 6.3 Pipelined Accesses 4-91
- 6.4 Using $\overline{\text{READY}}$ 4-97
- 6.5 Using $\overline{\text{BTERM}}$ 4-98
- 6.6 Unaligned Requests 4-100
- 6.7 Idle Bus 4-102

7.0 ON-CIRCUIT EMULATION ($\overline{\text{ONCE}}$™) 4-103

1.0 PURPOSE

This document provides a preview of the electrical characteristics expected of the 40, 33, 25 and 16 MHz versions of the 80960CA. For a detailed description of any 80960CA functional topic, other than parametric performance, consult the latest 80960CA Product Overview (Order No. 270669), or the 80960CA User's Manual (Order No. 270710).

2.0 80960CA OVERVIEW

The 80960CA is the second-generation member of the 80960 Family of embedded processors. The 80960CA is object code compatible with the 32-bit 80960 Core Architecture while including Special Function Register extensions to control on-chip peripherals, and instruction set extensions to shift 64-bit operands and configure on-chip hardware. Multiple 128-bit internal busses, on-chip instruction caching and a sophisticated instruction scheduler allow the processor to sustain execution of two instructions every clock, and peak at execution of 3 instructions per clock.

A 32-bit demultiplexed and pipelined burst bus provides a 160 Mbyte/s bandwidth to a system's high-speed external memory sub-system. In addition, the 80960CA's on-chip caching of instructions, procedure context and critical program data substantially decouples system performance from the wait states associated with accesses to the system's slower, cost sensitive, main memory sub-system.

The 80960CA bus controller also integrates full wait state and bus width control for highest system performance with minimal system design complexity. Unaligned access and Big Endian byte order support reduces the cost of porting existing applications to the 80960CA.

The processor also integrates four complete data-chaining DMA channels and a high-speed interrupt controller on-chip. The DMA channels perform: single-cycle or two-cycle transfers, data packing and unpacking, and data chaining. Block transfers, in addition to source or destination synchronized transfers are provided.

The interrupt controller provides full programmability of 248 interrupt sources into 32 priority levels with a typical interrupt task switch ("latency") time of 750 ns.

4

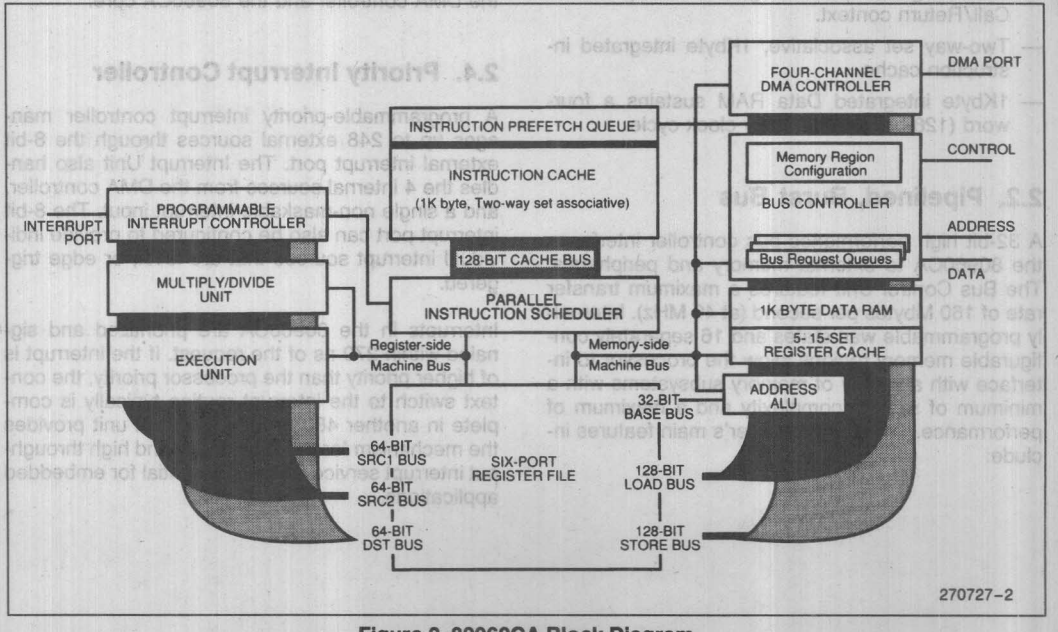


Figure 2. 80960CA Block Diagram

2.1. The C-Series Core

The C-Series core is a very high performance microarchitectural implementation of the 80960 Core Architecture. The C-Series core can sustain execution of two instructions per clock (66 MIPs at 33 MHz). To achieve this level of performance, Intel has incorporated state-of-the-art silicon technology and innovative microarchitectural constructs into the implementation of the C-Series core. Factors that contribute to the core's performance include:

— Advanced silicon technology allows operation with a 40 MHz internal clock.
— Parallel instruction decoding allows issue of up to three instructions per clock.
— Most instructions execute in a single clock.
— Parallel instruction decode allows sustained, simultaneous execution of two single-clock instructions every clock cycle.
— Efficient instruction pipeline is designed to minimize pipeline break losses.
— Register and resource scoreboarding allow simultaneous multi-clock instruction execution.
— Branch look-ahead and prediction allows many branches to execute with no pipeline break.
— Local Register Cache integrated on-chip caches Call/Return context.
— Two-way set associative, 1Kbyte integrated instruction cache
— 1Kbyte integrated Data RAM sustains a four-word (128-bit) access every clock cycle.

2.2. Pipelined, Burst Bus

A 32-bit high performance bus controller interfaces the 80960CA to external memory and peripherals. The Bus Control Unit features a maximum transfer rate of 160 Mbytes per second (at 40 MHz). Internally programmable wait states and 16 separately configurable memory regions allow the processor to interface with a variety of memory subsystems with a minimum of system complexity and a maximum of performance. The Bus Controller's main features include:

— Demultiplexed, Burst Bus to exploit most efficient DRAM access modes
— Address Pipelining to reduce memory cost while maintaining performance
— 32-, 16- and 8-bit modes for I/O interfacing ease.
— Full internal wait state generation to reduce system cost
— Little and Big Endian support to ease application development
— Unaligned access support for code portability
— Three-deep request queue to decouple the bus from the core
— Direct interface to Intel's 27C960 Burst EPROM and 82596 Ethernet Controller

2.3. Flexible DMA Controller

A four channel DMA controller provides high speed DMA control for data transfers involving peripherals and memory. The DMA provides advanced features such as data chaining, byte assembly and disassembly, and a high performance fly-by mode capable of transfer speed of up to 59 MBytes per second at 33 MHz. The DMA controller features a performance and flexibility which is only possible by integrating the DMA controller and the 80960CA core.

2.4. Priority Interrupt Controller

A programmable-priority interrupt controller manages up to 248 external sources through the 8-bit external interrupt port. The Interrupt Unit also handles the 4 internal sources from the DMA controller, and a single non-maskable interrupt input. The 8-bit interrupt port can also be configured to provide individual interrupt sources that are level, or edge triggered.

Interrupts in the 80960CA are prioritized and signaled within 270 ns of the request. If the interrupt is of higher priority than the processor priority, the context switch to the interrupt routine typically is complete in another 480 ns. The interrupt unit provides the mechanism for the low latency and high throughput interrupt service which is essential for embedded applications.

2.5. Instruction Set Summary

The following table summarizes the 80960CA instruction set by logical groupings. See the 80960CA User's Manual for a complete description of the instruction set.

Data Movement	Arithmetic	Logical	Bit, Bit Field and Byte
Load	Add	And	Set Bit
Store	Subtract	Not And	Clear Bit
Move	Multiply	And Not	Not Bit
Load Address	Divide	Or	Alter Bit
	Remainder	Exclusive Or	Scan for Bit
	Modulo	Not Or	Span over Bit
	Shift	Or Not	Extract
	*Extended Shift	Nor	Modify
	Extended Multiply	Exclusive Nor	Scan Byte for Equal
	Extended Divide	Not	
	Add with Carry	Nand	
	Subtract with Carry		
	Rotate		
Comparison	**Branch**	**Call and Return**	**Fault**
Compare	Unconditional Branch	Call	Conditional Fault
Conditional Compare	Conditional Branch	Call Extended	Synchronize Faults
Compare and Increment		Call System	
Compare and Decrement	Compare and Branch	Return	
Condition Test		Branch and Link	
Check Bit			
Debug	**Processor Management**	**Atomic**	
Modify Trace Controls	Modify Process Controls	Atomic Add	
Mark	Modify Arithmetic Controls	Atomic Modify	
Force Mark	*System Control		
	*DMA Control		
	Flush Local Registers		

NOTE:
Instructions marked by (*) are 80960CA extensions to the 80960 instruction set.

3.0 PACKAGE INFORMATION

3.1. Package Introduction

This section describes the pins, pinouts and thermal characteristics for the 80960CA in the 168-pin Ceramic Pin Grid Array (PGA) package and the 196 pin Plastic Quad Flat Package (PQFP). For complete package specifications and information, see the Intel Packaging Specification (Order # 231369).

3.2. Pin Descriptions

The 80960CA pins are described in this section. Table 1 presents the legend for interpreting the pin descriptions in the following tables.

The pins associated with the 32-bit demultiplexed processor bus are described in Table 2. The pins associated with basic processor configuration and control are described in Table 3. The pins associated with the 80960CA DMA Controller and Interrupt Unit are described in Table 4.

Figure 3 provides an example pin description table entry. The "I/O" signifies that the data pins are input-output. The "S" indicates the pins are synchronous to PCLK2:1. The "H(Z)" indicates that these pins float while the processor bus is in a Hold Acknowledge state. The "R(Z)" notation indicates that the pins also float while $\overline{\text{RESET}}$ is low.

All pins float while the processor is in the ONCE™ mode.

Table 1. Pin Description Nomenclature

Symbol	Description
I	Input only pin
O	Output only pin
I/O	Pin can be either an input or output
-	Pins "must be" connected as described
S(. . .)	Synchronous. Inputs must meet setup and hold times relative to PCLK2:1 for proper operation of the processor. All outputs are synchronous to PCLK2:1. S(E) Edge sensitive input S(L) Level sensitive input
A(. . .)	Asynchronous. Inputs may be asynchronous to PCLK2:1. A(E) Edge sensitive input A(L) Level sensitive input
H(. . .)	While the processor's bus is in the Hold Acknowledge state, the pin: H(1) is driven to V_{CC} H(0) is driven to V_{SS} H(Z) floats H(Q) continues to be a valid output
R(. . .)	While the processor's $\overline{\text{RESET}}$ # pin is low, the pin R(1) is driven to V_{CC} R(0) is driven to V_{SS} R(Z) floats R(Q) continues to be a valid output

Name	Type	Description
D31:0	I/O S(L) H(Z) R(Z)	**DATA BUS** carries 32, 16, or 8-bit data quantities depending on bus width configuration. The least significant bit of the data is carried on D0 and the most significant on D31. When the bus is configured for 8 bit data, the lower 8 data lines, D7:0 are used. For 16 bit data widths, D15:0 are used. For 32 bit data the full data bus is used.

Figure 3. Example Pin Description Entry

Table 2. 80960CA Pin Description—External Bus Signals

Name	Type	Description
A31:2	O S H(Z) R(Z)	**ADDRESS BUS** carries the upper 30 bits of the physical address. A31 is the most significant address bit and A2 is the least significant. During a bus access, A31:2 identify all external addresses to word (4-byte) boundaries. The byte enable signals indicate the selected byte in each word. During burst accesses, A3 and A2 increment to indicate successive data cycles.
D31:0	I / O S(L) H(Z) R(Z)	**DATA BUS** carries 32, 16, or 8-bit data quantities depending on bus width configuration. The least significant bit of the data is carried on D0 and the most significant on D31. When the bus is configured for 8 bit data, the lower 8 data lines, D7:0 are used. For 16 bit bus widths, D15:0 are used. For 32 bit bus widths the full data bus is used.
$\overline{BE3}$ **$\overline{BE2}$** **$\overline{BE1}$** **$\overline{BE0}$**	O S H(Z) R(I)	**BYTE ENABLES** select which of the four bytes addressed by A31:2 are active during an access to a memory region configured for a 32-bit data-bus width. $\overline{BE3}$ applies to D31:24; $\overline{BE2}$ applies to D23:16; $\overline{BE1}$ applies to D15:8; and $\overline{BE0}$ applies to D7:0. 32-bit bus: $\overline{BE3}$ –Byte Enable 3 –enable D31:24 $\overline{BE2}$ –Byte Enable 2 –enable D23:16 $\overline{BE1}$ –Byte Enable 1 –enable D15:8 $\overline{BE0}$ –Byte Enable 0 –enable D7:0 For accesses to a memory region configured for a 16-bit data-bus width, the processor directly encodes $\overline{BE3}$, $\overline{BE1}$ and $\overline{BE0}$ to provided $\overline{BHE}$, A1 and $\overline{BLE}$ respectively. 16-bit bus: $\overline{BE3}$ –Byte High Enable ($\overline{BHE}$) –enable D15:8 $\overline{BE2}$ –Not used (is driven high or low) $\overline{BE1}$ –Address Bit 1 (A1) $\overline{BE0}$ –Byte Low Enable ($\overline{BLE}$) –enable D7:0 For accesses to a memory region configured for an 8-bit data bus width, the processor directly encodes $\overline{BE1}$ and $\overline{BE0}$ to provide A1 and A0 respectively. 8-bit bus: $\overline{BE3}$ –Not used (is driven high or low) $\overline{BE2}$ –Not used (is driven high or low) $\overline{BE1}$ –Address Bit 1 (A1) $\overline{BE0}$ –Address Bit 0 (A0)
W/$\overline{R}$	O S H(Z) R(0)	**WRITE/READ** is low (0) for read accesses and high (1) for write accesses. The W/$\overline{R}$ signal changes in the same clock cycle as $\overline{ADS}$. It remains valid for the entire access in non-pipelined regions. In pipelined regions, W/$\overline{R}$ may not be valid in the last cycle of a read access.
$\overline{ADS}$	O S H(Z) R(1)	**ADDRESS STROBE** indicates valid address and the start of a new bus access. $\overline{ADS}$ is asserted for the first clock of a bus access.

4

Table 2. 80960CA Pin Description—External Bus Signals (Continued)

Name	Type	Description
$\overline{\text{READY}}$	I S(L) H(Z) R(Z)	**READY** is an input which signals the termination of a data transfer. $\overline{\text{READY}}$ is used to indicate that read data on the bus is valid, or that a write-data transfer has completed. The $\overline{\text{READY}}$ signal works in conjunction with the internally programmed wait-state generator. If $\overline{\text{READY}}$ is enabled in a region, the pin is sampled after the programmed number of wait-states has expired. If the $\overline{\text{READY}}$ pin is deasserted high, wait states will continue to be inserted until $\overline{\text{READY}}$ becomes asserted low. This is true for the N_{RAD}, N_{RDD}, N_{WAD}, and N_{WDD} wait states. The N_{XDA} wait states cannot be extended.
$\overline{\text{BTERM}}$	I S(L) H(Z) R(Z)	**BURST TERMINATE** is an input which signals the termination of an access. The assertion of $\overline{\text{BTERM}}$ causes another address cycle to occur. The $\overline{\text{BTERM}}$ signal works in conjunction with the internally programmed wait-state generator. If $\overline{\text{READY}}$ and $\overline{\text{BTERM}}$ are enabled in a region, the $\overline{\text{BTERM}}$ pin is sampled after the programmed number of wait states has expired. When $\overline{\text{BTERM}}$ is asserted (low), $\overline{\text{READY}}$ is ignored.
$\overline{\text{WAIT}}$	O S H(Z) R(1)	**WAIT** indicates the status of the internal wait state generator. $\overline{\text{WAIT}}$ is active when wait states are being caused by the internal wait state generator and not by the $\overline{\text{READY}}$ or $\overline{\text{BTERM}}$ inputs. $\overline{\text{WAIT}}$ can be used to derive a write-data strobe. $\overline{\text{WAIT}}$ can also be thought of as a $\overline{\text{READY}}$ output that the processor provides when it is inserting wait states.
$\overline{\text{BLAST}}$	O S H(Z) R(0)	**BURST LAST** indicates the last transfer in a bus access. $\overline{\text{BLAST}}$ is asserted in the last data transfer of burst and non-burst accesses after the wait state counter reaches zero. $\overline{\text{BLAST}}$ remains active until the clock following the last cycle of the last data transfer of a bus access. If the $\overline{\text{READY}}$ or $\overline{\text{BTERM}}$ input is used to extend wait states, the $\overline{\text{BLAST}}$ signal remains active until $\overline{\text{READY}}$ or $\overline{\text{BTERM}}$ terminates the access.
DT/$\overline{\text{R}}$	O S H(Z) R(0)	**DATA TRANSMIT/RECEIVE** indicates direction for data transceivers. DT/$\overline{\text{R}}$ is used in conjunction with $\overline{\text{DEN}}$ to provide control for data transceivers attached to the external bus. When DT/$\overline{\text{R}}$ is low (0), the signal indicates that the processor will receive data. Conversely, when high (1) the processor will send data. DT/$\overline{\text{R}}$ will change only while $\overline{\text{DEN}}$ is high.
$\overline{\text{DEN}}$	O S H(Z) R(1)	**DATA ENABLE** indicates data cycles in a bus access. $\overline{\text{DEN}}$ is asserted (low) at the start of the first data cycle of a bus request and is deasserted (high) at the end of the last data cycle. $\overline{\text{DEN}}$ is used in conjunction with DT/$\overline{\text{R}}$ to provide control for data transceivers attached to the external bus. $\overline{\text{DEN}}$ remains asserted for sequential reads from pipelined memory regions. $\overline{\text{DEN}}$ is high when DT/$\overline{\text{R}}$ changes.
$\overline{\text{LOCK}}$	O S H(Z) R(1)	**BUS LOCK** indicates that an atomic read-modify-write operation is in progress. $\overline{\text{LOCK}}$ may be used to prevent external agents from accessing memory which is currently involved in an atomic operation. $\overline{\text{LOCK}}$ is asserted (0) in the first clock of an atomic operation, and deasserted in the clock cycle following the last bus access for the atomic operation. To allow the most flexibility for a memory system enforcement of locked accesses, the processor will acknowledge a bus hold request when $\overline{\text{LOCK}}$ is asserted. The processor will perform DMA transfers while $\overline{\text{LOCK}}$ is active.
HOLD	I S(L) H(Z) R(Z)	**HOLD REQUEST** signals that an external agent requests access to the external bus. The processor asserts HOLDA after completing the current bus request. HOLD, HOLDA, and BREQ are used together to arbitrate access to the processor's external bus by external bus agents.
$\overline{\text{BOFF}}$	I S(L) H(Z) R(Z)	**BUS BACKOFF** causes the 80960CA to relinquish control of the bus and discontinue making bus requests. When $\overline{\text{BOFF}}$ is asserted, the bus controller aborts it current bus access and tri-states its address, data, and status lines. When the $\overline{\text{BOFF}}$ signal is deasserted, the 80960CA resumes by either regenerating the aborted access if one was in progress, or beginning the next access.

Table 2. 80960CA Pin Description—External Bus Signals (Continued)

Name	Type	Description
HOLDA	O S H(1) R(Q)	**HOLD ACKNOWLEDGE** indicates to a bus requestor that the processor has relinquished control of the external bus. When HOLDA is asserted, the external address bus, data bus, and bus control signals are floated. HOLD, HOLDA, and BREQ are used together to arbitrate access to the processor's external bus by external bus agents. Since the processor will grant HOLD requests and enter the Hold Acknowledge state even while $\overline{\text{RESET}}$ is active, the state of the HOLDA pin will be independent of the $\overline{\text{RESET}}$ pin.
BREQ	O S H(Q) R(0)	**BUS REQUEST** indicates that the processor wishes to perform a bus request. BREQ can be used by external bus arbitration logic in conjunction with HOLD and HOLDA to determine when to return mastership of the external bus to the processor.
D/$\overline{\text{C}}$	O S H(Z) R(Z)	**DATA OR CODE** indicates that a bus access is a data access (1) or a instruction access (0). D/$\overline{\text{C}}$ has the same timing as W/$\overline{\text{R}}$
$\overline{\text{DMA}}$	O S H(Z) R(Z)	**DMA ACCESS** indicates whether the bus access was initiated by the DMA controller. $\overline{\text{DMA}}$ will be asserted (low) for any DMA access. $\overline{\text{DMA}}$ will be deasserted (high) for all other accesses.
$\overline{\text{SUP}}$	O S H(Z) R(Z)	**SUPERVISOR ACCESS** indicates whether the bus access originates from a request issued while in supervisor mode. $\overline{\text{SUP}}$ will be asserted (low) when the access has supervisor privileges, and will be deasserted (high) otherwise. $\overline{\text{SUP}}$ can be used to isolate supervisor code and data structures from non-supervisor access.

Table 3. 80960CA Pin Description—Processor Control Signals

Name	Type	Description
$\overline{\text{RESET}}$	I A(L) H(Z) R(Z) N(Z)	**RESET** causes the chip to reset. When $\overline{\text{RESET}}$ is asserted (low), all external signals return to the reset state. When $\overline{\text{RESET}}$ is deasserted, initialization begins. When the two-x clock mode is selected, $\overline{\text{RESET}}$ must remain asserted for 16 PCLK2:1 cycles before being deasserted in order to guarantee correct initialization of the processor. When the one-x clock mode is selected, $\overline{\text{RESET}}$ must remain asserted for 10,000 PCLK2:1 cycles before being deasserted in order to guarantee correct initialization of the processor. The CLKMODE pin selects one-x or two-x input clock division of the CLKIN pin. The processor's Hold Acknowledge bus state functions while the chip is reset. If the processor's bus is in the Hold Acknowledge state when $\overline{\text{RESET}}$ is activated, the processor will internally reset, but will maintain the Hold Acknowledge state on external pins until the Hold request is removed. If a hold request is made while the processor is in the reset state, the processor bus will grant HOLDA and enter the Hold Acknowledge state.
$\overline{\text{FAIL}}$	O S H(Q) R(0)	**FAIL** indicates failure of the processor's self-test performed at initialization. When $\overline{\text{RESET}}$ is deasserted and the processor begins initialization, the $\overline{\text{FAIL}}$ pin is asserted (0). An internal self-test is performed as part of the initialization process. If this self-test passes, the $\overline{\text{FAIL}}$ pin is deasserted (1) otherwise it remains asserted. The $\overline{\text{FAIL}}$ pin is reasserted while the processor performs and external bus self-confidence test. If this self-test passes, the processor deasserts the $\overline{\text{FAIL}}$ pin and branches to the users initialization routine, otherwise the $\overline{\text{FAIL}}$ pin remains asserted. Internal self-test and the use of the $\overline{\text{FAIL}}$ pin can be disabled with the STEST pin.

Table 3. 80960CA Pin Description—Processor Control Signals (Continued)

Name	Type	Description
STEST	I S(L) H(Z) R(Z)	**SELF TEST** causes the processor's internal self-test feature to be enabled or disabled at initialization. STEST is read on the rising edge of $\overline{\text{RESET}}$. When asserted (high) the processor's internal self-test and external bus confidence tests are performed during processor initialization. When deasserted (low), only the internal self-test is not performed during initialization.
$\overline{\text{ONCE}}$™	I A(L) H(Z) R(Z)	**ON CIRCUIT EMULATION** causes all outputs to be floated when asserted (low). $\overline{\text{ONCE}}$ is continuously sampled while $\overline{\text{RESET}}$ is low, and is latched on the rising edge of $\overline{\text{RESET}}$. To place the processor in the ONCE state: (1) assert $\overline{\text{RESET}}$ and $\overline{\text{ONCE}}$ (order does not matter) (2) wait for at least 16 clocks in one-x mode, or 10,000 clocks in two-x mode, after V_{CC} and CLKIN are within operating specifications (3) deassert $\overline{\text{RESET}}$ (4) wait at least 16 clocks (The processor will now be latched in the ONCE state as long as $\overline{\text{RESET}}$ is high.) To exit the ONCE state, bring V_{CC} and CLKIN to operating conditions, then assert $\overline{\text{RESET}}$ and bring $\overline{\text{ONCE}}$ high prior to deasserting $\overline{\text{RESET}}$. CLKIN must operate within the specified operating conditions of the processor until step 4 above has been completed. The CLKIN may then be changed to D.C. to achieve the lowest possible ONCE mode leakage current. $\overline{\text{ONCE}}$ can be used by emulator products or for board testers to effectively make an installed processor transparent in the board.
CLKIN	I A(E) H(Z) R(Z)	**CLOCK INPUT** is an input for the external clock needed to run the processor. The external clock is internally divided as prescribed by the CLKMODE pin to produce PCLK2:1.
CLKMODE	I A(L) H(Z) R(Z)	**CLOCK MODE** selects the division factor applied to the external clock input (CLKIN). When CLKMODE is high (1), CLKIN is divided by one to create PCLK2:1 and the processor's internal clock. When CLKMODE is low (0), CLKIN is divided by two to create PCLK2:1 and the processor's internal clock. CLKMODE should be tied high, or low in a system, as the clock mode is not latched by the processor. If left unconnected, the processor will internally pull the CLKMODE pin low (0), enabling the two-x clock mode.
PCLK2 **PCLK1**	O S H(Q) R(Q)	**PROCESSOR OUTPUT CLOCKS** provide a timing reference for all inputs and outputs of the processor. All inputs and output timings are specified in relation to PCLK2 and PCLK1. PCLK2 and PCLK1 are identical signals. Two output pins are provided to allow flexibility in the system's allocation of capacitive loading on the clock. PCLK2:1 may also be connected at the processor to form a single clock signal.
V_{SS}	–	**GROUND** connections consist of 24 pins which must be connected externally to a V_{SS} board plane.
V_{CC}	–	**POWER** connections consist of 24 pins which must be connected externally to a V_{CC} board plane.
N/C	–	**NO CONNECT** pins must not be connected in a system.

Table 4. 80960CA Pin Description—DMA and Interrupt Unit Control Signals

Name	Type	Description
DREQ3 DREQ2 DREQ1 DREQ0	I A(L) H(Z) R(Z)	**DMA REQUEST** causes a DMA transfer to be requested. Each of the four signals requests a transfer on a single channel. DREQ0 requests channel 0, DREQ1 requests channel 1, etc. When two or more channels are requested simultaneously, the channel with the highest priority is serviced first. The channel priority mode is programmable.
DACK3 DACK2 DACK1 DACK0	O S H(Z) R(1)	**DMA ACKNOWLEDGE** indicates that a DMA transfer is being executed. Each of the four signals acknowledges a transfer for a single channel. DACK0 acknowledges channel 0, DACK1 acknowledges channel 1, etc. DACK3:0 are active (0) when the requesting device of a DMA is accessed.
EOP3/TC3 EOP2/TC2 EOP1/TC1 EOP0/TC0	I / O A(L) H(Z/Q) R(Z)	**END OF PROCESS/TERMINAL COUNT** can be programmed as either an input (EOP3:0) or as an output (TC3:0), but not both. Each pin is individually programmable. When programmed as an input, EOPx causes the termination of a current DMA transfer for the channel corresponding to the EOPx pin. EOP0 corresponds to channel 0, EOP1 corresponds to channel 1, etc. When a channel is configured for source *and* destination chaining, the EOP pin for that channel causes termination of only the current buffer transferred and causes the next buffer to be transferred. EOP3:0 are asynchronous inputs. When programmed as an output, the channel's TCx pin indicates that the channel byte count has reached 0 and a DMA has terminated. TCx is driven active (0) for a single clock cycle after the last DMA transfer is completed on the external bus. TC3:0 are synchronous outputs.
XINT7 XINT6 XINT5 XINT4 XINT3 XINT2 XINT1 XINT0	I A(E/L) H(Z) R(Z)	**EXTERNAL INTERRUPT PINS** cause interrupts to be requested. These pins can be configured in three modes. In the Dedicated Mode, each pin is a dedicated external interrupt source. Dedicated inputs can be individually programmed to be level (low) or edge (falling) activated. In the Expanded Mode, the 8 pins act together as an 8-bit vectored interrupt source. The interrupt pins in this mode are level activated. Since the interrupt pins are active low, the vector number requested is the one's complement of the positive logic value place on the port. This eliminates glue logic to interface to combinational priority encoders which output negative logic. In the Mixed Mode, XINT7:5 are dedicated sources and XINT4:0 act as the 5 most significant bits of an expanded mode vector. The least significant bits are set to 010 internally.
NMI	I A(E) H(Z) R(Z)	**NON-MASKABLE INTERRUPT** causes a non-maskable interrupt event to occur. NMI is the highest priority interrupt recognized. NMI is an edge (falling) activated source.

4

3.3. 80960CA Pinout

3.3.1 80960CA CPGA PINOUT

Tables 5 and 6 list the 80960CA pin names with package location. Figure 4-a depicts the complete 80960CA pinout as viewed from the top side of the component (i.e., pins facing down). Figure 4-b shows the complete 80960CA pinout as viewed from the pin-side of the package (i.e., pins facing up). See **Section 4.0, Electrical Specifications** for specifications and recommended connections.

Table 5. Pin Name with Package Location

Address Bus	Data Bus	Bus Control	Processor Control	I/O
Name . . Location	*Name . . Location*	*Name . . Location*	*Name . . . . Location*	*Name . . Location*
A31 . . . . . S15	D31 . . . . . R03	$\overline{BE3}$ S05	$\overline{RESET}$ A16	$\overline{DREQ3}$ A07
A30 . . . . . Q13	D30 . . . . . Q05	$\overline{BE2}$ S06		$\overline{DREQ2}$ B06
A29 . . . . . R14	D29 . . . . . S02	$\overline{BE1}$ S07	$\overline{FAIL}$ A02	$\overline{DREQ1}$ A06
A28 . . . . . Q14	D28 . . . . . Q04	$\overline{BE0}$ R09		$\overline{DREQ0}$ B05
A27 . . . . . S16	D27 . . . . . R02		STEST B02	
A26 . . . . . R15	D26 . . . . . Q03	W/$\overline{R}$ S10		$\overline{DACK3}$ A10
A25 . . . . . S17	D25 . . . . . S01		$\overline{ONCE}$ C03	$\overline{DACK2}$ A09
A24 . . . . . Q15	D24 . . . . . R01	$\overline{ADS}$ R06		$\overline{DACK1}$ A08
A23 . . . . . R16	D23 . . . . . Q02		CKLIN C13	$\overline{DACK0}$ B08
A22 . . . . . R17	D22 . . . . . P03	$\overline{READY}$ S03	CLKMODE C14	
A21 . . . . . Q16	D21 . . . . . Q01	$\overline{BTERM}$ R04	PCLK1 . . . . . B14	EOP/$\overline{TC0}$ . . . A11
A20 . . . . . P15	D20 . . . . . P02		PCLK2 . . . . . B13	EOP/$\overline{TC1}$ . . . A12
A19 . . . . . P16	D19 . . . . . P01	$\overline{WAIT}$ S12		EOP/$\overline{TC2}$ . . . A13
A18 . . . . . Q17	D18 . . . . . N02	$\overline{BLAST}$ S08	**V_{SS}**	EOP/$\overline{TC3}$ . . . A14
A17 . . . . . P17	D17 . . . . . N01		*Location*	
A16 . . . . . N16	D16 . . . . . M01	DT/$\overline{R}$ S11	C07, C08, C09, C10, C11, C12, F15, G03, G15, H03, H15, J03, J15, K03, K15, L03, L15, M03, M15, Q07, Q08, Q09, Q10, Q11	$\overline{XINT7}$ C17
A15 . . . . . N17	D15 . . . . . L01	$\overline{DEN}$ S09		$\overline{XINT6}$ C16
A14 . . . . . M17	D14 . . . . . L02			$\overline{XINT5}$ B17
A13 . . . . . L16	D13 . . . . . K01	$\overline{LOCK}$ S14		$\overline{XINT4}$ C15
A12 . . . . . L17	D12 . . . . . J01			$\overline{XINT3}$ B16
A11 . . . . . K17	D11 . . . . . H01	HOLD R05		$\overline{XINT2}$ A17
A10 . . . . . J17	D10 . . . . . H02	HOLDA S04	**V_{CC}**	$\overline{XINT1}$ A15
A9 . . . . . H17	D9 . . . . . G01	BREQ R13	*Location*	$\overline{XINT0}$ B15
A8 . . . . . G17	D8 . . . . . F01		B07, B09, B10, B11, B12, C06, E15, F03, F16, G02, H16, J02, J16, K02, K16, M02, M16, N03, N15, Q06, R07, R08, R10, R11	
A7 . . . . . G16	D7 . . . . . E01	D/$\overline{C}$ S13		$\overline{NMI}$ D15
A6 . . . . . F17	D6 . . . . . F02	$\overline{DMA}$ R12		
A5 . . . . . E17	D5 . . . . . D01	$\overline{SUP}$ Q12		
A4 . . . . . E16	D4 . . . . . E02			
A3 . . . . . D17	D3 . . . . . C01	$\overline{BOFF}$ B01	**No Connect**	
A2 . . . . . D16	D2 . . . . . D02		*Location*	
	D1 . . . . . C02		A01, A03, A04, A05, B03, B04, C04, C05, D03	
	D0 . . . . . E03			

Table 6. Pin Name with Package Location

Address Bus	Data Bus	Bus Control	Processor Control	I/O
Location . . Name	*Location . . Name*	*Location . . Name*	*Location . . . . Name*	*Location . . Name*
A01 . . . . . NC	C01 . . . . . D3	G01 . . . . . D9	M01 . . . . . D16	R01 . . . . . D24
A02 . . . . . $\overline{FAIL}$	C02 . . . . . D1	G02 . . . . . V_{CC}	M02 . . . . . V_{CC}	R02 . . . . . D27
A03 . . . . . NC	C03 . . . . . $\overline{ONCE}$	G03 . . . . . V_{SS}	M03 . . . . . V_{SS}	R03 . . . . . D31
A04 . . . . . NC	C04 . . . . . NC	G15 . . . . . V_{SS}	M15 . . . . . V_{SS}	R04 . . . . . $\overline{BTERM}$
A05 . . . . . NC	C05 . . . . . NC	G16 . . . . . A7	M16 . . . . . V_{CC}	R05 . . . . . HOLD
A06 . . . . . $\overline{DREQ1}$	C06 . . . . . V_{CC}	G17 . . . . . A8	M17 . . . . . A14	R06 . . . . . $\overline{ADS}$
A07 . . . . . $\overline{DREQ3}$	C07 . . . . . V_{SS}			R07 . . . . . V_{CC}
A08 . . . . . $\overline{DACK1}$	C08 . . . . . V_{SS}	H01 . . . . . D11	N01 . . . . . D17	R08 . . . . . V_{CC}
A09 . . . . . $\overline{DACK2}$	C09 . . . . . V_{SS}	H02 . . . . . D10	N02 . . . . . D18	R09 . . . . . $\overline{BE0}$
A10 . . . . . $\overline{DACK3}$	C10 . . . . . V_{SS}	H03 . . . . . V_{SS}	N03 . . . . . V_{CC}	R10 . . . . . V_{CC}
A11 . . . $\overline{EOP/TC0}$	C11 . . . . . V_{SS}	H15 . . . . . V_{SS}	N15 . . . . . V_{CC}	R11 . . . . . V_{CC}
A12 . . . $\overline{EOP/TC1}$	C12 . . . . . V_{SS}	H16 . . . . . V_{CC}	N16 . . . . . A16	R12 . . . . . $\overline{DMA}$
A13 . . . $\overline{EOP/TC2}$	C13 . . . . . CLKIN	H17 . . . . . A9	N17 . . . . . A15	R13 . . . . . BREQ
A14 . . . $\overline{EOP/TC3}$	C14 . . CLKMODE			R14 . . . . . A29
A15 . . . . . $\overline{XINT1}$	C15 . . . . . $\overline{XINT4}$	J01 . . . . . D12	P01 . . . . . D19	R15 . . . . . A26
A16 . . . . . $\overline{RESET}$	C16 . . . . . $\overline{XINT6}$	J02 . . . . . V_{CC}	P02 . . . . . D20	R16 . . . . . A23
A17 . . . . . $\overline{XINT2}$	C17 . . . . . $\overline{XINT7}$	J03 . . . . . V_{SS}	P03 . . . . . D22	R17 . . . . . A22
		J15 . . . . . V_{SS}	P15 . . . . . A20	
B01 . . . . . $\overline{BOFF}$	D01 . . . . . D5	J16 . . . . . V_{CC}	P16 . . . . . A19	S01 . . . . . D25
B02 . . . . . STEST	D02 . . . . . D2	J17 . . . . . A10	P17 . . . . . A17	S02 . . . . . D29
B03 . . . . . NC	D03 . . . . . NC			S03 . . . . . $\overline{READY}$
B04 . . . . . NC	D15 . . . . . $\overline{NMI}$	K01 . . . . . D13	Q01 . . . . . D21	S04 . . . . . HOLDA
B05 . . . . . $\overline{DREQ0}$	D16 . . . . . A2	K02 . . . . . V_{CC}	Q02 . . . . . D23	S05 . . . . . $\overline{BE3}$
B06 . . . . . $\overline{DREQ2}$	D17 . . . . . A3	K03 . . . . . V_{SS}	Q03 . . . . . D26	S06 . . . . . $\overline{BE2}$
B07 . . . . . V_{CC}		K15 . . . . . V_{SS}	Q04 . . . . . D28	S07 . . . . . $\overline{BE1}$
B08 . . . . . $\overline{DACK0}$	E01 . . . . . D7	K16 . . . . . V_{CC}	Q05 . . . . . D30	S08 . . . . . $\overline{BLAST}$
B09 . . . . . V_{CC}	E02 . . . . . D4	K17 . . . . . A11	Q06 . . . . . V_{CC}	S09 . . . . . $\overline{DEN}$
B10 . . . . . V_{CC}	E03 . . . . . D0		Q07 . . . . . V_{SS}	S10 . . . . . W/$\overline{R}$
B11 . . . . . V_{CC}	E15 . . . . . V_{CC}	L01 . . . . . D15	Q08 . . . . . V_{SS}	S11 . . . . . DT/$\overline{R}$
B12 . . . . . V_{CC}	E16 . . . . . A4	L02 . . . . . D14	Q09 . . . . . V_{SS}	S12 . . . . . $\overline{WAIT}$
B13 . . . . . PCLK2	E17 . . . . . A5	L03 . . . . . V_{SS}	Q10 . . . . . V_{SS}	S13 . . . . . D/$\overline{C}$
B14 . . . . . PCLK1		L15 . . . . . V_{SS}	Q11 . . . . . V_{SS}	S14 . . . . . $\overline{LOCK}$
B15 . . . . . $\overline{XINT0}$	F01 . . . . . D8	L16 . . . . . A13	Q12 . . . . . $\overline{SUP}$	S15 . . . . . A31
B16 . . . . . $\overline{XINT3}$	F02 . . . . . D6	L17 . . . . . A12	Q13 . . . . . A30	S16 . . . . . A27
B17 . . . . . $\overline{XINT5}$	F03 . . . . . V_{CC}		Q14 . . . . . A28	S17 . . . . . A25
	F15 . . . . . V_{SS}		Q15 . . . . . A24	
	F16 . . . . . V_{CC}		Q16 . . . . . A21	
	F17 . . . . . A6		Q17 . . . . . A18	

4

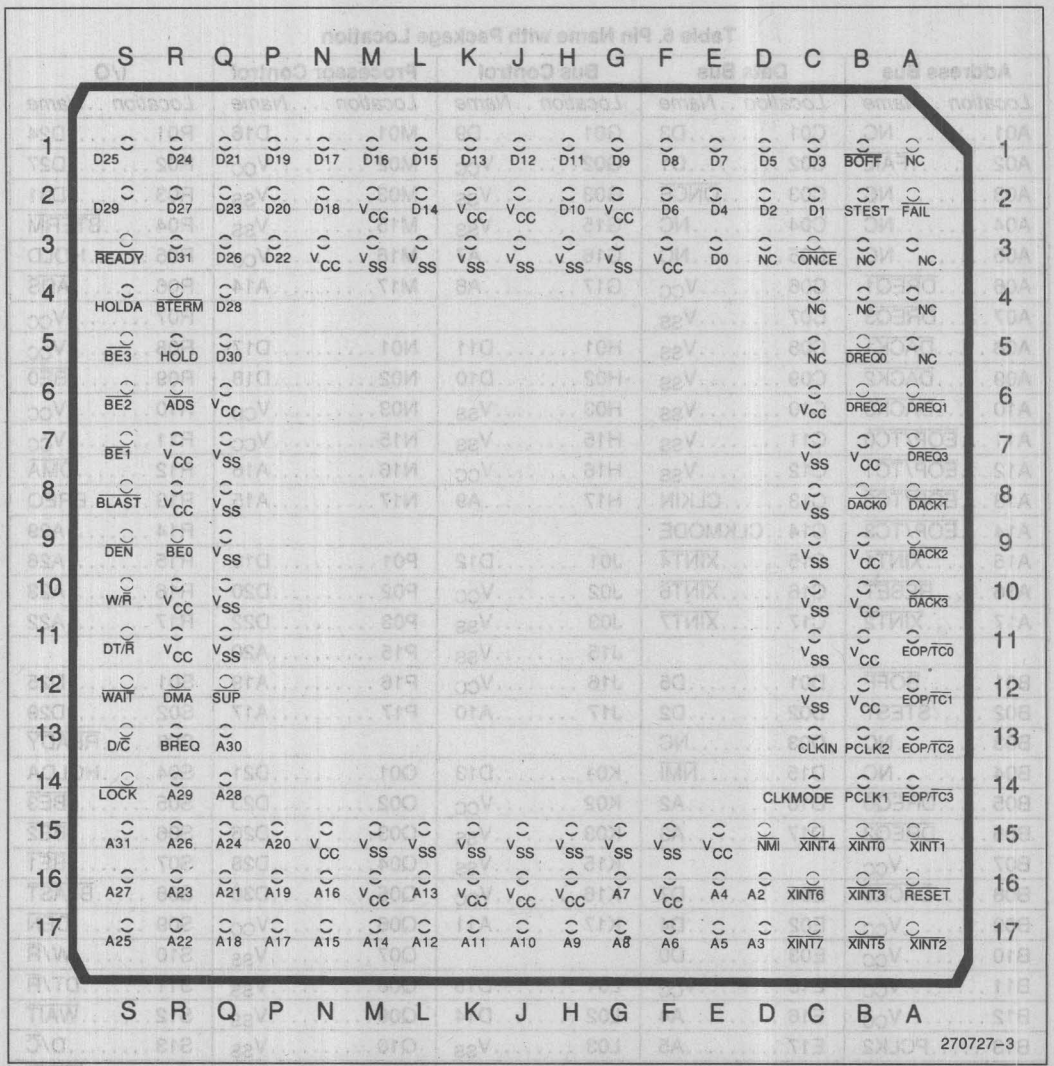


Figure 4a. 80960CA PGA Pinout (View from Top Side)

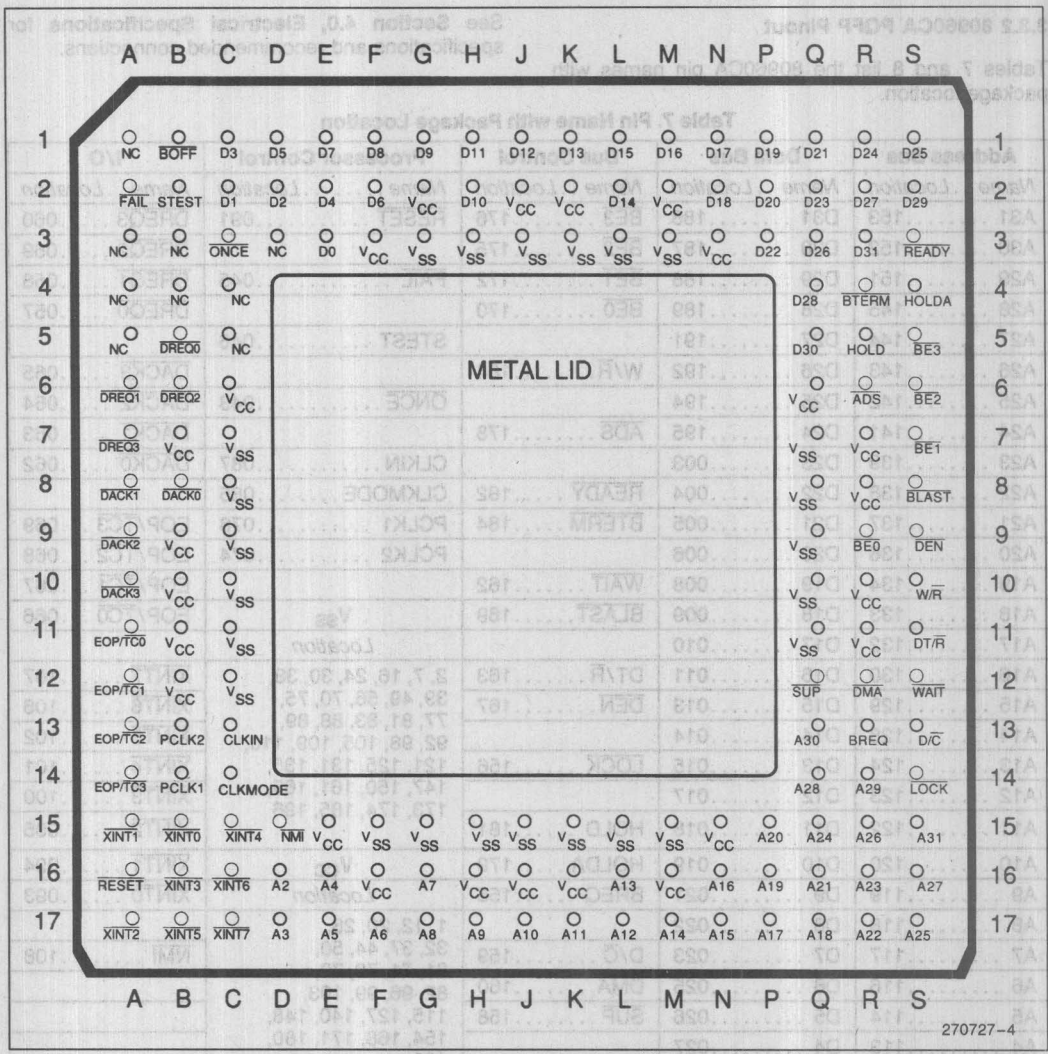


Figure 4b. 80960CA PGA Pinout (View from Bottom Side)

3.3.2 80960CA PQFP Pinout

Tables 7 and 8 list the 80960CA pin names with package location.

See **Section 4.0, Electrical Specifications** for specifications and recommended connections.

Table 7. Pin Name with Package Location

Address Bus	Data Bus	Bus Control	Processor Control	I/O
Name . . Location	*Name . . Location*	*Name . . Location*	*Name . . . . . Location*	*Name . . Location*
A31 153	D31 186	$\overline{BE3}$ 176	$\overline{RESET}$ 091	$\overline{DREQ3}$ 060
A30 152	D30 187	$\overline{BE2}$ 175		$\overline{DREQ2}$ 059
A29 151	D29 188	$\overline{BE1}$ 172	$\overline{FAIL}$ 045	$\overline{DREQ1}$ 058
A28 145	D28 189	$\overline{BE0}$ 170		$\overline{DREQ0}$ 057
A27 144	D27 191		STEST 046	
A26 143	D26 192	W/$\overline{R}$ 164		$\overline{DACK3}$ 065
A25 142	D25 194		$\overline{ONCE}$ 043	$\overline{DACK2}$ 064
A24 141	D24 195	$\overline{ADS}$ 178		$\overline{DACK1}$ 063
A23 139	D23 003		CLKIN 087	$\overline{DACK0}$ 062
A22 138	D22 004	$\overline{READY}$ 182	CLKMODE 085	
A21 137	D21 005	$\overline{BTERM}$ 184	PCLK1 078	EOP/$\overline{TC3}$ . . . 069
A20 136	D20 006		PCLK2 074	EOP/$\overline{TC2}$ . . . 068
A19 134	D19 008	$\overline{WAIT}$ 162		EOP/$\overline{TC1}$ . . . 067
A18 133	D18 009	$\overline{BLAST}$ 169	**V_{SS}**	EOP/$\overline{TC0}$ . . . 066
A17 132	D17 010		*Location*	
A16 130	D16 011	DT/$\overline{R}$ 163	2, 7, 16, 24, 30, 38, 39, 49, 56, 70, 75, 77, 81, 83, 88, 89, 92, 98, 105, 109, 110, 121, 125, 131, 135, 147, 150, 161, 165, 173, 174, 185, 196	$\overline{XINT7}$ 107
A15 129	D15 013	$\overline{DEN}$ 167		$\overline{XINT6}$ 106
A14 128	D14 014			$\overline{XINT5}$ 102
A13 124	D13 015	$\overline{LOCK}$ 156		$\overline{XINT4}$ 101
A12 123	D12 017			$\overline{XINT3}$ 100
A11 122	D11 018	HOLD 181		$\overline{XINT2}$ 095
A10 120	D10 019	HOLDA 179	**V_{CC}**	$\overline{XINT1}$ 094
A9 119	D9 021	BREQ 155	*Location*	$\overline{XINT0}$ 093
A8 118	D8 022		1, 12, 20, 28, 32, 37, 44, 50, 61, 71, 72, 79, 82, 96, 99, 103, 115, 127, 140, 148, 154, 168, 171, 180, 190	
A7 117	D7 023	D/$\overline{C}$ 159		$\overline{NMI}$ 108
A6 116	D6 025	$\overline{DMA}$ 160		
A5 114	D5 026	$\overline{SUP}$ 158		
A4 113	D4 027			
A3 112	D3 033	$\overline{BOFF}$ 040	**No Connect**	
A2 111	D2 034		*Location*	
	D1 035		29, 41, 42, 47, 48, 51, 52, 53, 54, 55, 73, 76, 80, 84, 86, 90, 97, 104, 126, 146, 149, 157, 166, 177, 183, 193	
	D0 036			

11	D16	60	DREQ3	109	V_{SS}	158	$\overline{SUP}$
12	V_{CC}	61	V_{CC}	110	V_{SS}	159	D/$\overline{C}$
13	D15	62	$\overline{DACK0}$	111	A2	160	$\overline{DMA}$
14	D14	63	$\overline{DACK1}$	112	A3	161	V_{SS}
15	D13	64	$\overline{DACK2}$	113	A4	162	$\overline{WAIT}$
16	V_{SS}	65	$\overline{DACK3}$	114	A5	163	DT/$\overline{R}$
17	D12	66	EOP0/$\overline{TC0}$	115	V_{CC}	164	W/$\overline{R}$
18	D11	67	EOP1/$\overline{TC1}$	116	A6	165	V_{SS}
19	D10	68	EOP2/$\overline{TC2}$	117	A7	166	NC
20	V_{CC}	69	EOP3/$\overline{TC3}$	118	A8	167	$\overline{DEN}$
21	D9	70	V_{SS}	119	A9	168	V_{CC}
22	D8	71	V_{CC}	120	A10	169	$\overline{BLAST}$
23	D7	72	V_{CC}	121	V_{SS}	170	$\overline{BE0}$
24	V_{SS}	73	NC	122	A11	171	V_{CC}
25	D6	74	PCLK2	123	A12	172	$\overline{BE1}$
26	D5	75	V_{SS}	124	A13	173	V_{SS}
27	D4	76	NC	125	V_{SS}	174	V_{SS}
28	V_{CC}	77	V_{SS}	126	NC	175	$\overline{BE2}$
29	NC	78	PCLK1	127	V_{CC}	176	$\overline{BE3}$
30	V_{SS}	79	V_{CC}	128	A14	177	NC
31	NC	80	NC	129	A15	178	$\overline{ADS}$
32	V_{CC}	81	V_{SS}	130	A16	179	HLDA
33	D3	82	V_{CC}	131	V_{SS}	180	V_{CC}
34	D2	83	V_{SS}	132	A17	181	HOLD
35	D1	84	NC	133	A18	182	$\overline{READY}$
36	D0	85	CLKMODE	134	A19	183	NC
37	V_{CC}	86	NC	135	V_{SS}	184	$\overline{BTERM}$
38	V_{SS}	87	CLKIN	136	A20	185	V_{SS}
39	V_{SS}	88	V_{SS}	137	A21	186	D31
40	$\overline{BOFF}$	89	V_{SS}	138	A22	187	D30
41	NC	90	NC	139	A23	188	D29
42	NC	91	$\overline{RESET}$	140	V_{CC}	189	D28
43	$\overline{ONCE}$	92	V_{SS}	141	A24	190	V_{CC}
44	V_{CC}	93	$\overline{XINT0}$	142	A25	191	D27
45	$\overline{FAIL}$	94	$\overline{XINT1}$	143	A26	192	D26
46	STEST	95	$\overline{XINT2}$	144	A27	193	NC
47	NC	96	V_{CC}	145	A28	194	D25
48	NC	97	NC	146	NC	195	D24
49	V_{SS}	98	V_{SS}	147	V_{SS}	196	V_{SS}

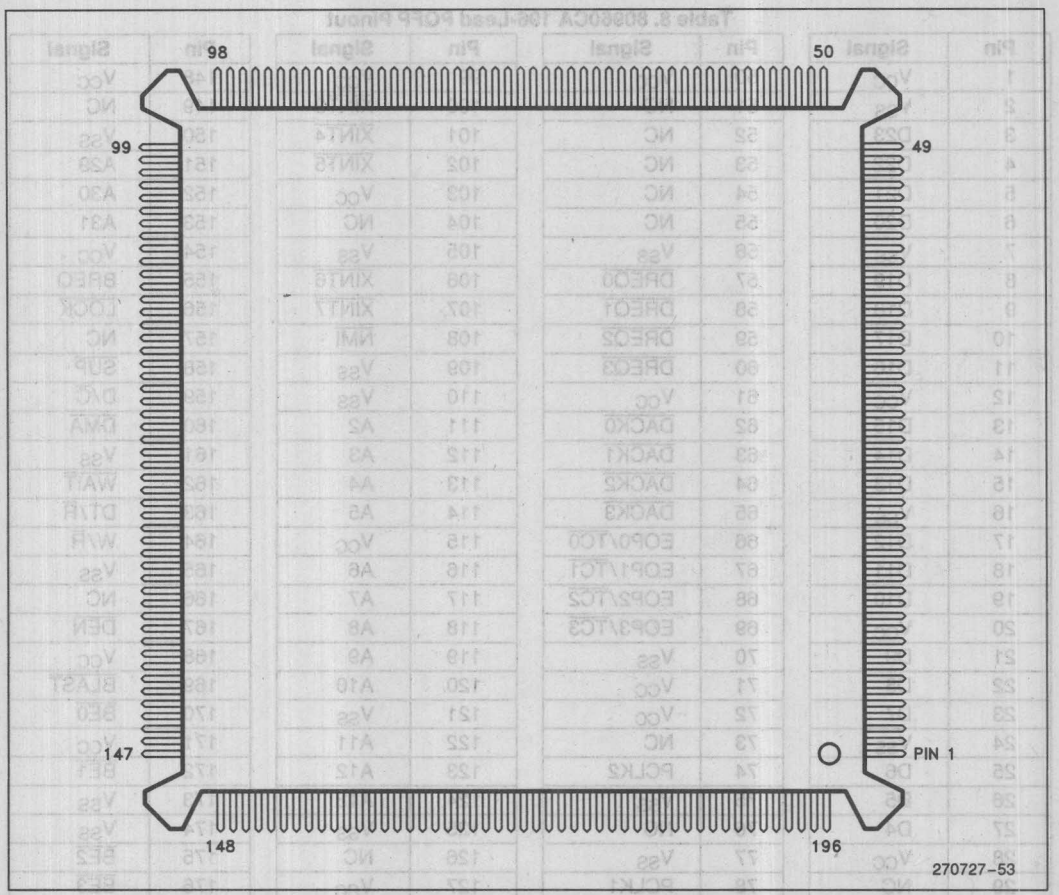
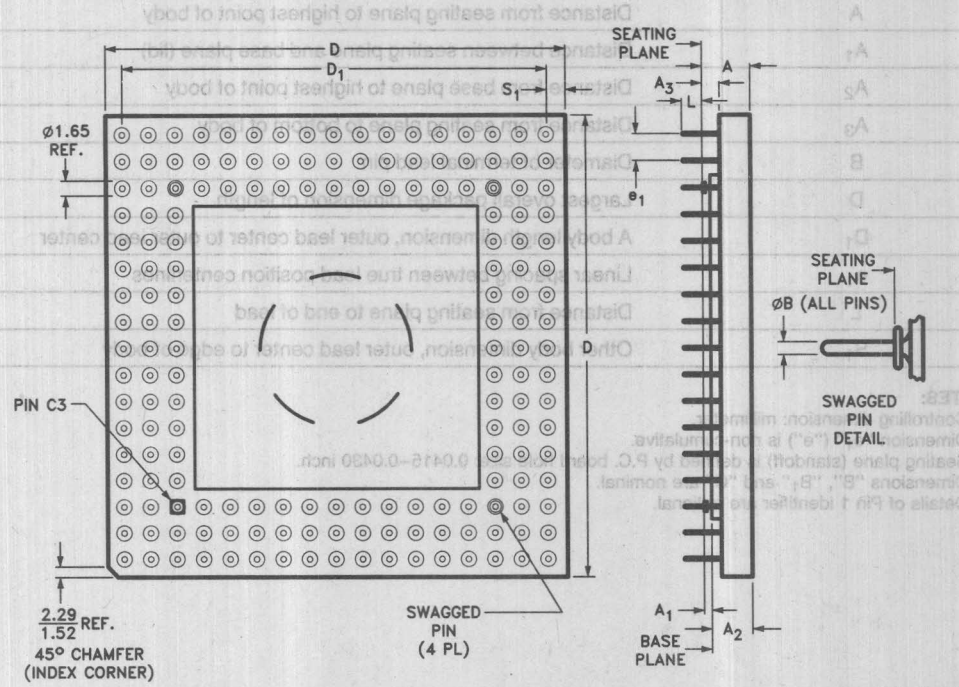


Figure 4c. 80960CA PQFP Pinout (View from Top Side)

3.4. Mechanical Data

3.4.1 CERAMIC PGA PACKAGE



Family: Ceramic Pin Grid Array Package						
Symbol	Millimeters			Inches		
	Min	Max	Notes	Min	Max	Notes
A	3.56	4.57		0.140	0.180	
A_1	0.64	1.14	SOLID LID	0.025	0.045	SOLID LID
A_2	23	0.30	SOLID LID	0.110	0.140	SOLID LID
A_3	1.14	1.40		0.045	0.055	
B	0.43	0.51		0.017	0.020	
D	44.07	44.83		1.735	1.765	
D_1	40.51	40.77		1.595	1.605	
e_1	2.29	2.79		0.090	0.110	
L	2.54	3.30		0.100	0.130	
N	168			168		
S_1	1.52	2.54		0.060	0.100	
ISSUE	IWS REV X 7/15/88					

Figure 5. 168 Lead Ceramic PGA Package Dimensions

Table 9. Ceramic PGA Package Dimension Symbols

Letter or Symbol	Description of Dimensions
A	Distance from seating plane to highest point of body
A_1	Distance between seating plane and base plane (lid)
A_2	Distance from base plane to highest point of body
A_3	Distance from seating plane to bottom of body
B	Diameter of terminal lead pin
D	Largest overall package dimension of length
D_1	A body length dimension, outer lead center to outer lead center
e_1	Linear spacing between true lead position centerlines
L	Distance from seating plane to end of lead
S_1	Other body dimension, outer lead center to edge of body

NOTES:
1. Controlling dimension: millimeter.
2. Dimension "e_1" ("e") is non-cumulative.
3. Seating plane (standoff) is defined by P.C. board hole size: 0.0415–0.0430 inch.
4. Dimensions "B", "B_1" and "C" are nominal.
5. Details of Pin 1 identifier are optional.

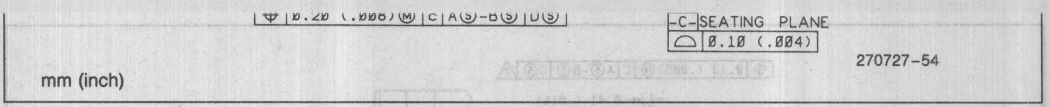


Figure 6. Principal Dimensions and Datums

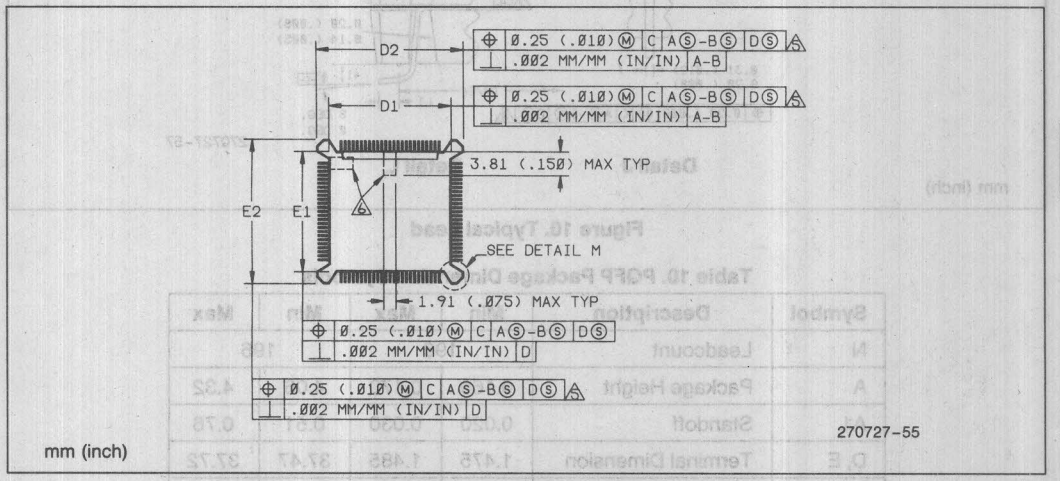


Figure 7. Molded Details

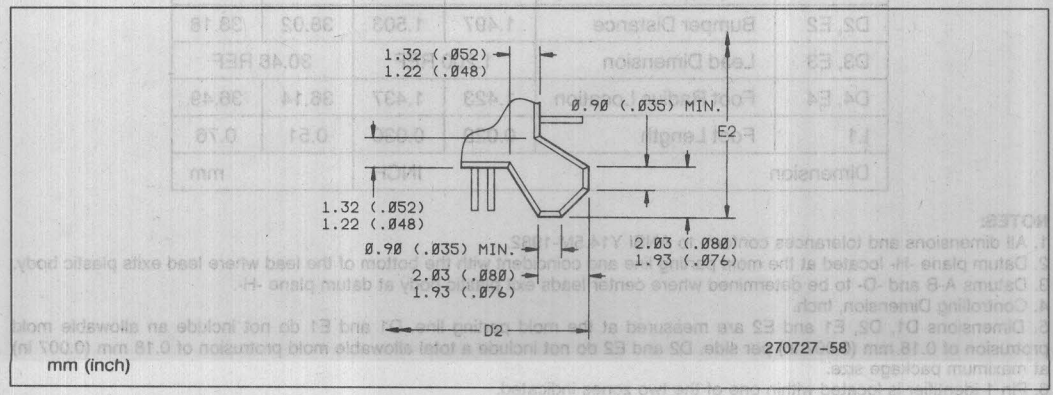
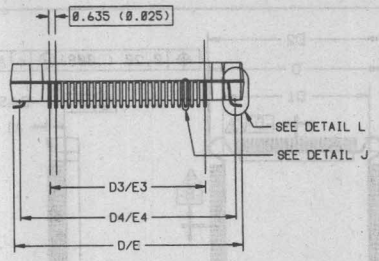


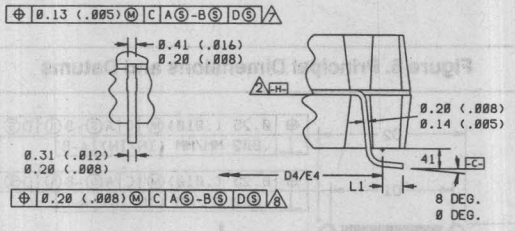
Figure 8. Detail M



270727-56

mm (inch)

Figure 9. Terminal Details



270727-57

Detail J **Detail L**

mm (inch)

Figure 10. Typical Lead

Table 10. PQFP Package Dimension Symbols

Symbol	Description	Min	Max	Min	Max
N	Leadcount	196		196	
A	Package Height	0.160	0.170	4.06	4.32
A1	Standoff	0.020	0.030	0.51	0.76
D, E	Terminal Dimension	1.475	1.485	37.47	37.72
D1, E1	Package Body	1.347	1.353	34.21	34.37
D2, E2	Bumper Distance	1.497	1.503	38.02	38.18
D3, E3	Lead Dimension	1.200 REF		30.48 REF	
D4, E4	Foot Radius Location	1.423	1.437	36.14	36.49
L1	Foot Length	0.020	0.030	0.51	0.76
Dimension			INCH		mm

NOTES:
1. All dimensions and tolerances conform to ANSI Y14.5M-1982.
2. Datum plane -H- located at the mold parting line and coincident with the bottom of the lead where lead exits plastic body.
3. Datums A-B and -D- to be determined where center leads exit plastic body at datum plane -H-.
4. Controlling Dimension, Inch.
5. Dimensions D1, D2, E1 and E2 are measured at the mold parting line. D1 and E1 do not include an allowable mold protrusion of 0.18 mm (0.007 in) per side. D2 and E2 do not include a total allowable mold protrusion of 0.18 mm (0.007 in) at maximum package size.
6. Pin 1 identifier is located within one of the two zones indicated.
7. Measured at datum plane -H-.
8. Measured at seating plane datum -C-.

3.5. Package Thermal Specifications

The 80960CA is specified for operation when T_C (the case temperature) is within the range of 0°C–100°C. T_C may be measured in any environment to determine whether the 80960CA is within specified operating range. The case temperature should be measured at the center of the top surface, opposite the pins. Refer to Figure 11.

T_A (the ambient temperature) can be calculated from θ_{CA} (thermal resistance from case to ambient) with the following equation:

$$T_A = T_C - P^*\theta_{CA}$$

Table 11 shows the maximum T_A allowable (without exceeding T_C) at various airflows and operating frequencies (f_{PCLK}).

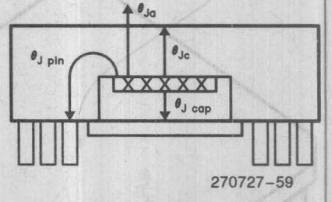
Note that T_A is greatly improved by attaching fins or a heat sink to the package. P (the maximum power consumption) is calculated by using the maximum I_{CC} as tabulated in Section 4.4, **DC Characteristics**, and V_{CC} of 5V.

Table 11. Maximum T_A at Various Airflows In °C (PGA Package Only)

		Airflow-ft/min (m/sec)					
	f_{PCLK} (MHz)	0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
T_A with Heat Sink*	33	64	75	84	86	89	90
	25	70	79	87	88	91	92
	16	80	86	91	92	94	95
T_A without Heat Sink	33	53	61	69	75	80	81
	25	61	68	75	79	84	85
	16	74	79	83	86	89	90

* 0.285″ high unidirectional heat sink (Al alloy 6061, 50 mil fin width, 150 mil center-to-center fin spacing).

PGA Thermal Resistance—°C/Watt						
Parameter	Airflow—ft./min (m/sec)					
	0 (0)	200 (1.01)	400 (2.03)	600 (3.07)	800 (4.06)	1000 (5.07)
θ Junction-to-Case (Case Measured as shown in Figure 13)	1.5	1.5	1.5	1.5	1.5	1.5
θ Case-to-Ambient (No Heatsink)	17	14	11	9	7.1	6.6
θ Case-to-Ambient (with Unidirectional) Heatsink)*	13	9	5.5	5.0	3.9	3.4



270727-59

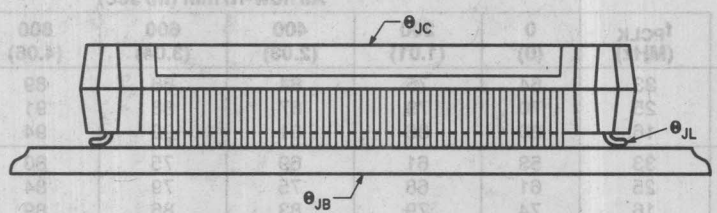
NOTES:
1. This table applies to 80960CA PGA plugged into socket or soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. $\theta_{J\text{-}CAP}$ = 4°C/W (approx.)
   $\theta_{J\text{-}PIN}$ = 4°C/W (inner pins) (approx.)
   $\theta_{J\text{-}PIN}$ = 8°C/W (outer pins) (approx.)

* 0.285″ high unidirectional heat sink (Al alloy 6061, 50 mil fin width, 150 mil center-to-center fin spacing).

Figure 11. 80960CA PGA Package Thermal Characteristics

PQFP Thermal Resistance—°C/Watt							
Parameter	Airflow—ft./min (m/sec)						
	0 (0)	50 (0.25)	100 (0.50)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)
θ Junction-to-Case (Case Measured) as shown in Figure 13)	5	5	5	5	5	5	5
θ Case-to-Ambient (No Heatsink)	17	18	17	15	12	10	9

NOTES:
1. This table applies to 80960CA PQFP soldered directly into board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.
3. $\theta_{JL} = 18°C/Watt$
   $\theta_{JB} = 18°C/Watt$



270727-60

Figure 12. 80960CA PQFP Package Thermal Characteristics

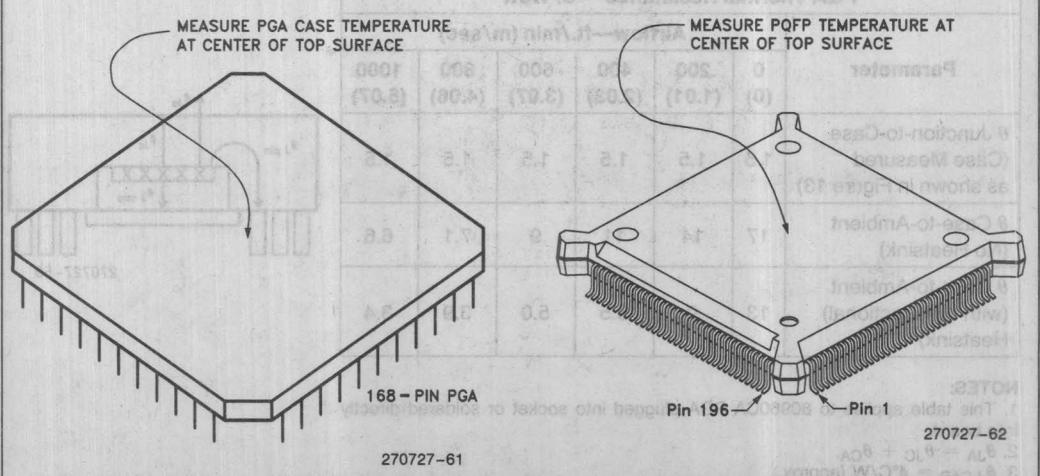


Figure 13. Measuring 80960CA PGA and PQFP Case Temperature

4.0 ELECTRICAL SPECIFICATIONS

NOTICE: This data sheet contains preliminary information on new products in production. The specifications are subject to change without notice.

4.1. Absolute Maximum Ratings

Parameter	Maximum Rating
Storage Temperature	−65 °C to +150 °C
Case Temperature Under Bias	−65 °C to +110 °C
Supply Voltage wrt. V_{SS}	−0.5V to +6.5V
Voltage on Other pins wrt V_{SS}	−0.5V to V_{CC} +0.5V

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

4.2. Operating Conditions

Operating Conditions (80960CA-40, -33, -25, -16)

Symbol	Parameter		Min	Max	Units	Notes
V_{CC}	Supply Voltage		4.5	5.5	V	
f_{CLK2x}	Input Clock Frequency (2-x Mode)	80960CA-40	0	80	MHz	
		80960CA-33	0	66	MHz	
		80960CA-25	0	50	MHz	
		80960CA-16	0	32	MHz	
f_{CLK1x}	Input Clock Frequency (1-x Mode)	80960CA-40	8	40	MHz	
		80960CA-33	8	33	MHz	
		80960CA-25	8	25	MHz	(1)
		80960CA-16	8	16	MHz	
T_C	Case Temperature Under Bias	80960CA-40, -33, -25, -16	0	100	°C	

NOTE:
(1) When in the 1-x input clock mode, CLKIN is an input to an internal phase-locked loop and must maintain a minimum frequency of 8 MHz for proper processor operation. However, in the 1-x Mode, CLKIN may still be stopped when the processor either is in a reset condition or is reset. If CLKIN is stopped, the specified $\overline{\text{RESET}}$ low time must be provided once CLKIN restarts and has stabilized.

4.3. Recommended Connections

Power and ground connections must be made to multiple V_{CC} and V_{SS} (GND) pins. Every 80960CA-based circuit board should include power (V_{CC}) and ground (V_{SS}) planes for power distribution. Every V_{CC} pin must be connected to the power plane, and every V_{SS} pin must be connected to the ground plane. Pins identified as "N.C." **must not** be connected in the system.

Liberal decoupling capacitance should be placed near the 80960CA. The processor can cause transient power surges when its numerous output buffers transition, particularly when connected to large capacitive loads.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the processor and decoupling capacitors as much as possible. Capacitors specifically designed for PGA packages will offer the lowest possible inductance.

For reliable operation, always connect unused inputs to an appropriate signal level. In particular, any unused interrupt ($\overline{\text{XINT}}$, $\overline{\text{NMI}}$) or DMA ($\overline{\text{DREQ}}$) input should be connected to V_{CC} through a pull-up resistor, as should $\overline{\text{BTERM}}$ if not used. Pull-up resistors should be in the range of 20 KΩ for each pin tied high. If $\overline{\text{READY}}$ or HOLD are not used, the unused input should be connected to ground. **N.C. pins must always remain unconnected.** Refer to the 80960CA User's Manual for more information.

***NOTICE:** The information in this datasheet is a preliminary version of expected device performance. This information is subject to change without notice. Once qualification information corresponding to a production device is available, an updated datasheet will be published to supercede this document.*

4.4. D.C. Specifications

D.C. Characteristics

(80960CA-40, -33, -25, -16 under the conditions described in **Section 4.2, Operating Conditions.**)

Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage for all pins except $\overline{RESET}$	−0.3	0.8	V	
V_{IH}	Input High Voltage for all pins except $\overline{RESET}$	2.0	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage		0.45	V	I_{OL} = 5 mA
V_{OH}	Output High Voltage I_{OH} = −1mA I_{OH} = −200µA	2.4 V_{CC} − 0.5		V V	
V_{ILR}	Input Low Voltage for $\overline{RESET}$	− 0.3	1.5	V	
V_{IHR}	Input High Voltage for $\overline{RESET}$	3.5	V_{CC} + 0.3	V	
V_{RH}	Input Hysterisis on $\overline{RESET}$	0.35	0.65	V	
I_{LI1}	Input Leakage Current for each pin *except*: $\overline{BTERM}$, $\overline{ONCE}$, $\overline{DREQ3:0}$, EOP3:0/$\overline{TC3:0}$, $\overline{NMI}$, $\overline{XINT7:0}$, $\overline{READY}$, HOLD, $\overline{BOFF}$		±15	µA	0V≤V_{IN}≤V_{CC} (1)
I_{LI2}	Input Leakage Current for: $\overline{BTERM}$, $\overline{ONCE}$, $\overline{DREQ3:0}$, EOP3:0/$\overline{TC3:0}$, $\overline{NMI}$, $\overline{XINT7:0}$, $\overline{READY}$, $\overline{BOFF}$	0	300	µA	V_{IN} = 0.45V (2)
I_{LI3}	Input Leakage Current for: $\overline{READY}$, HOLD	0	500	µA	V_{IN} = 2.4V (3)
I_{LO}	Output Leakage Current		±15	µA	0.45V≤V_{OUT}≤V_{CC}
I_{CC}	Supply Current (A80960CA-40) I_{CC}		1200	mA	(4)
I_{CC}	Supply Current (A80960CA-33) I_{CC}		900	mA	(4)
I_{CC}	Supply Current (80960CA-25) I_{CC}		700	mA	(4)
I_{CC}	Supply Current (80960CA-16) I_{CC}		500	mA	(4)
I_{ONCE}	ONCE-mode Supply Current		100	mA	
C_{IN}	Input Capacitance for: CLKIN, $\overline{RESET}$, $\overline{ONCE}$, $\overline{READY}$, HOLD, $\overline{DREQ3:0}$, $\overline{BOFF}$ $\overline{XINT7:0}$, $\overline{NMI}$, $\overline{BTERM}$, CLKMODE	0	12	pF	FC = 1 MHz
C_{OUT}	Output Capacitance of each output pin		12	pF	F_C = 1 MHz, (5)
$C_{I/O}$	I/O Pin Capacitance		12	pF	F_C = 1 MHz

NOTES:
(1) No Pull-up or pull-down.
(2) These pins have internal pullup resistors.
(3) These pins have internal pulldown resistors.
(4) Measured at worst case frequency, V_{CC} and temperature, with device operating and outputs loaded to the test conditions described in **Section 4.5.2, A.C. Test Conditions.**
(5) Output Capacitance is the capacitive load of a floating output pin.

4.5. A.C. Specifications

4.5.1. A.C. SPECIFICATION TABLES

A.C. Characteristics — 80960CA-40

(80960CA-40 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions**.)

Symbol	Parameter		Min	Max	Units	Notes
	INPUT CLOCK(10)					
T_F	CLKIN Frequency		0	80	MHz	(1)
T_C	CLKIN Period	In One-X Mode (f_{CLK1x})	25	125	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	12.5	∞	ns	(1)
T_{CS}	CLKIN Period Stability	In One-X Mode (f_{CLK1x})		±0.1%	Δ	(1,13)
T_{CH}	CLKIN High Time	In One-X Mode (f_{CLK1x})	5	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	5	∞	ns	(1)
T_{CL}	CLKIN Low Time	In One-X Mode (f_{CLK1x})	5		ns	(1,12)
		In Two-X Mode (f_{CLK2x})	5	∞	ns	(1)
T_{CR}	CLKIN Rise Time		0	6	ns	(1)
T_{CF}	CLKIN Fall Time		0	6	ns	(1)
	OUTPUT CLOCKS(9)					
T_{CP}	CLKIN to PCLK2:1 Delay	In One-X Mode (f_{CLK1x})	−2	2	ns	(1,3,13)
		In Two-X Mode (f_{CLK2x})	2	25	ns	(1,3)
T	PCLK2:1 Period	In One-X Mode (f_{CLK1x})	T_C		ns	(1,13)
		In Two-X Mode (f_{CLK2x})	$2T_C$		ns	(1,3)
T_{PH}	PCLK2:1 High Time		(T/2) − 2	T/2	ns	(1,13)
T_{PL}	PCLK2:1 Low Time		(T/2) − 2	T/2	ns	(1,13)
T_{PR}	PCLK2:1 Rise Time		1	4	ns	(1,3)
T_{PF}	PCLK2:1 Fall Time		1	4	ns	(1,3)
	SYNCHRONOUS OUTPUTS(9)					
T_{OV} T_{OH}	Output Valid Delay, Output Hold					(6, 11)
	T_{OV1}, T_{OH1}	A31:28	3	12	ns	
	T_{OV2}, T_{OH2}	A27:4	3	12	ns	
	T_{OV3}, T_{OH3}	A3:2	3	12	ns	
	T_{OV4}, T_{OH4}	$\overline{BE3:0}$	3	14	ns	
	T_{OV5}, T_{OH5}	$\overline{ADS}$	6	16	ns	
	T_{OV6}, T_{OH6}	W/$\overline{R}$	3	16	ns	
	T_{OV7}, T_{OH7}	D/$\overline{C}$,$\overline{SUP}$,$\overline{DMA}$	4	14	ns	
	T_{OV8}, T_{OH8}	$\overline{BLAST}$, $\overline{WAIT}$	6	14	ns	
	T_{OV9}, T_{OH9}	$\overline{DEN}$	3	14	ns	
	T_{OV10}, T_{OH10}	HOLDA, $\overline{BREQ}$	4	14	ns	
	T_{OV11}, T_{OH11}	$\overline{LOCK}$	4	14	ns	
	T_{OV12}, T_{OH12}	$\overline{DACK3:0}$, EOP3:0/$\overline{TC3:0}$	4	16	ns	
	T_{OV13}, T_{OH13}	D31:0	3	14	ns	
	T_{OV14}, T_{OH14}	DT/$\overline{R}$	T/2 + 3	T/2 + 12	ns	
T_{OF}	Output Float for all outputs		3	22	ns	(6)
	SYNCHRONOUS INPUTS(10)					
T_{IS}	Input Setup					
	T_{IS1}	D31:0	3		ns	(1,11)
	T_{IS2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	7		ns	(1,11)
	T_{IS3}	HOLD	7		ns	(1,11)
T_{IH}	Input Hold					
	T_{IH1}	D31:0	3		ns	(1,11)
	T_{IH2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	3		ns	(1,11)
	T_{IH3}	HOLD	3		ns	(1,11)

A.C. Characteristics — 80960CA-40

80960CA-40 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions**.) (Continued)

Symbol	Parameter	Min	Max	Units	Notes
	RELATIVE OUTPUT TIMINGS(9,7)				
T_{AVSH1}	A31:2 Valid to $\overline{ADS}$ Rising	T − 4	T + 4	ns	
T_{AVSH2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, D/$\overline{C}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{ADS}$ Rising	T − 6	T + 6	ns	
T_{AVEL1}	A31:2 Valid to $\overline{DEN}$ Falling	T − 4	T + 4	ns	
T_{AVEL2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, $\overline{INST}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{DEN}$ Falling	T − 6	T + 6	ns	
T_{NLQV}	$\overline{WAIT}$ Falling to Output Data Valid	±4		ns	
T_{DVNH}	Output Data Valid to $\overline{WAIT}$ Rising	N*T − 4	2N*T + 4	ns	(4)
T_{NLNH}	$\overline{WAIT}$ Falling to $\overline{WAIT}$ Rising	N*T ± 4		ns	(4)
T_{NHQX}	Output Data Hold after $\overline{WAIT}$ Rising	N*T − 4	N*T + 4	ns	(5)
T_{EHQX}	Output Data Hold after $\overline{DEN}$ Rising	− 6	∞	ns	(6)
T_{EHTV}	DT/$\overline{R}$ Hold after $\overline{DEN}$ High	T/2 − 4	∞	ns	(6)
T_{TVEL}	DT/$\overline{R}$ Valid to $\overline{DEN}$ Falling	T/2 − 4	T/2 + 4	ns	(7)
T_{DTS}	Outputs Valid to Tristate	T/2	T/2 + 10	ns	(7)
T_{TSD}	Tristate to Outputs Valid	T/2	T/2 + 10	ns	(7)
	RELATIVE INPUT TIMINGS(7)				
T_{IS4}	$\overline{RESET}$ Input Setup	4		ns	(8)
T_{IH4}	$\overline{RESET}$ Input Hold	3		ns	(8)
T_{IS5}	$\overline{DREQ3:0}$ Input Setup	10		ns	(8)
T_{IH5}	$\overline{DREQ3:0}$ Input Hold	5		ns	(8)

NOTES:

(1) See **Section 4.5.3, A.C. Timing Waveforms** for waveforms and definitions.
(2) See Figure 20 for capacitive derating information for output delays and hold times.
(3) See Figure 21 for capacitive derating information for rise and fall times.
(4) Where N is the number of wait states that are inserted by the Bus Controller Region Table. When there are no wait states in an access, $\overline{WAIT}$ never goes active.
(5) N = Number of wait states inserted with $\overline{READY}$.
(6) Output Data and/or DT/$\overline{R}$ may be driven indefinitely following a cycle if there is no subsequent bus activity.
(7) See Notes 1, 2, and 3.
(8) Since asynchronous inputs are synchronized internally by the 80960CA they have no required setup or hold times in order to be recognized and for proper operation. However, in order to guarantee recognition of the input at a particular rising edge of PCLK2:1 the setup times shown must be met. Asynchronous inputs must be active for at least two consecutive PCLK2:1 rising edges to be seen by the processor.
(9) These specifications are guaranteed by the processor.
(10) These specifications must be met by the system for proper operation of the processor.
(11) This timing is dependent upon the loading of PCLK2:1. Use the derating curves of **Section 4.5.3** to adjust the timing for PCLK2:1 loading.
(12) In the One-x input clock mode the maximum input clock period is limited to 125 ns while the processor is operating. When the processor is in reset, the input clock may stop even in One-x mode.
(13) When in the One-x input clock mode, these specifications assume a stable input clock with a period variation of less than ±0.1% between adjacent cycles.

A.C. Characteristics — 80960CA-33

(80960CA-33 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions.**)

Symbol	Parameter		Min	Max	Units	Notes
	INPUT CLOCK(10)					
T_F	CLKIN Frequency		0	66	MHz	(1)
T_C	CLKIN Period	In One-X Mode (f_{CLK1x})	30.3	125	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	15.15	∞	ns	(1)
T_{CS}	CLKIN Period Stability	In One-X Mode (f_{CLK1x})		±0.1%	Δ	(1,13)
T_{CH}	CLKIN High Time	In One-X Mode (f_{CLK1x})	6	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	6	∞	ns	(1)
T_{CL}	CLKIN Low Time	In One-X Mode (f_{CLK1x})	6	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	6	∞	ns	(1)
T_{CR}	CLKIN Rise Time		0	6	ns	(1)
T_{CF}	CLKIN Fall Time		0	6	ns	(1)
	OUTPUT CLOCKS(9)					
T_{CP}	CLKIN to PCLK2:1 Delay	In One-X Mode (f_{CLK1x})	−2	2	ns	(1,3,13)
		In Two-X Mode (f_{CLK2x})	2	25	ns	(1,3)
T	PCLK2:1 Period	In One-X Mode (f_{CLK1x})	T_C		ns	(1,13)
		In Two-X Mode (f_{CLK2x})	$2T_C$		ns	(1,3)
T_{PH}	PCLK2:1 High Time		(T/2) − 2	T/2	ns	(1,13)
T_{PL}	PCLK2:1 Low Time		(T/2) − 2	T/2	ns	(1,13)
T_{PR}	PCLK2:1 Rise Time		1	4	ns	(1,3)
T_{PF}	PCLK2:1 Fall Time		1	4	ns	(1,3)
	SYNCHRONOUS OUTPUTS(8)					
T_{OV} T_{OH}	Output Valid Delay, Output Hold					(6, 11)
	T_{OV1}, T_{OH1}	A31:28	3	14	ns	
	T_{OV2}, T_{OH2}	A27:4	3	14	ns	
	T_{OV3}, T_{OH3}	A3:2	3	14	ns	
	T_{OV4}, T_{OH4}	$\overline{BE3:0}$	3	16	ns	
	T_{OV5}, T_{OH5}	$\overline{ADS}$	6	18	ns	
	T_{OV6}, T_{OH6}	W/$\overline{R}$	3	18	ns	
	T_{OV7}, T_{OH7}	D/$\overline{C}$,$\overline{SUP}$,$\overline{DMA}$	4	16	ns	
	T_{OV8}, T_{OH8}	$\overline{BLAST}$, $\overline{WAIT}$	6	16	ns	
	T_{OV9}, T_{OH9}	$\overline{DEN}$	3	16	ns	
	T_{OV10}, T_{OH10}	HOLDA, $\overline{BREQ}$	4	16	ns	
	T_{OV11}, T_{OH11}	$\overline{LOCK}$	4	16	ns	
	T_{OV12}, T_{OH12}	$\overline{DACK3:0}$, EOP3:0/TC3:0	4	18	ns	
	T_{OV13}, T_{OH13}	D31:0	3	16	ns	
	T_{OV14}, T_{OH14}	DT/$\overline{R}$	T/2 + 3	T/2 + 14	ns	
T_{OF}	Output Float for all outputs		3	22	ns	(6)
	SYNCHRONOUS INPUTS(10)					
T_{IS}	Input Setup					
	T_{IS1}	D31:0	3		ns	(1,11)
	T_{IS2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	7		ns	(1,11)
	T_{IS3}	HOLD	7		ns	(1,11)
T_{IH}	Input Hold					
	T_{IH1}	D31:0	3		ns	(1,11)
	T_{IH2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	5		ns	(1,11)
	T_{IH3}	HOLD	3		ns	(1,11)

4

A.C. Characteristics — 80960CA-33

80960CA-33 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions.**) (Continued)

Symbol	Parameter	Min	Max	Units	Notes
	RELATIVE OUTPUT TIMINGS(9,7)				
T_{AVSH1}	A31:2 Valid to $\overline{ADS}$ Rising	T − 4	T + 4	ns	
T_{AVSH2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, D/$\overline{C}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{ADS}$ Rising	T − 6	T + 6	ns	
T_{AVEL1}	A31:2 Valid to $\overline{DEN}$ Falling	T − 4	T + 4	ns	
T_{AVEL2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, $\overline{INST}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{DEN}$ Falling	T − 6	T + 6	ns	
T_{NLQV}	$\overline{WAIT}$ Falling to Output Data Valid	±4		ns	
T_{DVNH}	Output Data Valid to $\overline{WAIT}$ Rising	N*T − 4	2N*T + 4	ns	(4)
T_{NLNH}	$\overline{WAIT}$ Falling to $\overline{WAIT}$ Rising	N*T ± 4		ns	(4)
T_{NHQX}	Output Data Hold after $\overline{WAIT}$ Rising	N*T − 4	N*T + 4	ns	(5)
T_{EHQX}	Output Data Hold after $\overline{DEN}$ Rising	− 4	∞	ns	(6)
T_{EHTV}	DT/$\overline{R}$ Hold after $\overline{DEN}$ High	T/2 − 4	∞	ns	(6)
T_{TVEL}	DT/$\overline{R}$ Valid to $\overline{DEN}$ Falling	T/2 − 4	T/2 + 4	ns	(7)
T_{DTS}	Outputs Valid to Tristate	T/2	T/2 + 10	ns	(7)
T_{TSD}	Tristate to Outputs Valid	T/2	T/2 + 10	ns	(7)
	RELATIVE INPUT TIMINGS(7)				
T_{IS4}	$\overline{RESET}$ Input Setup	6		ns	(8)
T_{IH4}	$\overline{RESET}$ Input Hold	5		ns	(8)
T_{IS5}	$\overline{DREQ3:0}$ Input Setup	12		ns	(8)
T_{IH5}	$\overline{DREQ3:0}$ Input Hold	7		ns	(8)

NOTES:
(1) See **Section 4.5.3, A.C. Timing Waveforms** for waveforms and definitions.
(2) See Figure 20 for capacitive derating information for output delays and hold times.
(3) See Figure 21 for capacitive derating information for rise and fall times.
(4) Where N is the number of wait states that are inserted by the Bus Controller Region Table. When there are no wait states in an access, $\overline{WAIT}$ never goes active.
(5) N = Number of wait states inserted with $\overline{READY}$.
(6) Output Data and/or DT/$\overline{R}$ may be driven indefinitely following a cycle if there is no subsequent bus activity.
(7) See Notes 1, 2, and 3.
(8) Since asynchronous inputs are synchronized internally by the 80960CA they have no required setup or hold times in order to be recognized and for proper operation. However, in order to guarantee recognition of the input at a particular rising edge of PCLK2:1 the setup times shown must be met. Asynchronous inputs must be active for at least two consecutive PCLK2:1 rising edges to be seen by the processor.
(9) These specifications are guaranteed by the processor.
(10) These specifications must be met by the system for proper operation of the processor.
(11) This timing is dependent upon the loading of PCLK2:1. Use the derating curves of **Section 4.5.3** to adjust the timing for PCLK2:1 loading.
(12) In the One-x input clock mode the maximum input clock period is limited to 125 ns while the processor is operating. When the processor is in reset, the input clock may stop even in One-x mode.
(13) When in the One-x input clock mode, these specifications assume a stable input clock with a period variation of less than ±0.1% between adjacent cycles.

A.C. Characteristics — 80960CA-25

(80960CA-25 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions.**)

Symbol	Parameter		Min	Max	Units	Notes
	INPUT CLOCK(10)					
T_F	CLKIN Frequency		0	50	MHz	(1)
T_C	CLKIN Period	In One-X Mode (f_{CLK1x})	40	125	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	20	∞	ns	(1)
T_{CS}	CLKIN Period Stability	In One-X Mode (f_{CLK1x})		±0.1%	Δ	(1,13)
T_{CH}	CLKIN High Time	In One-X Mode (f_{CLK1x})	8	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	8	∞	ns	(1)
T_{CL}	CLKIN Low Time	In One-X Mode (f_{CLK1x})	8	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	8	∞	ns	(1)
T_{CR}	CLKIN Rise Time		0	6	ns	(1)
T_{CF}	CLKIN Fall Time		0	6	ns	(1)
	OUTPUT CLOCKS(9)					
T_{CP}	CLKIN to PCLK2:1 Delay	In One-X Mode (f_{CLK1x})	−2	2	ns	(1,3,13)
		In Two-X Mode (f_{CLK2x})	2	25	ns	(1,3)
T	PCLK2:1 Period	In One-X Mode (f_{CLK1x})	T_C		ns	(1,13)
		In Two-X Mode (f_{CLK2x})	$2T_C$		ns	(1,3)
T_{PH}	PCLK2:1 High Time		(T/2) − 3	T/2	ns	(1,13)
T_{PL}	PCLK2:1 Low Time		(T/2) − 3	T/2	ns	(1,13)
T_{PR}	PCLK2:1 Rise Time		1	4	ns	(1,3)
T_{PF}	PCLK2:1 Fall Time		1	4	ns	(1,3)
	SYNCHRONOUS OUTPUTS(9)					
T_{OV}	Output Valid Delay, Output Hold					(6, 11)
T_{OH}	T_{OV1}, T_{OH1}	A31:28	3	16	ns	
	T_{OV2}, T_{OH2}	A27:4	3	16	ns	
	T_{OV3}, T_{OH3}	A3:2	3	16	ns	
	T_{OV4}, T_{OH4}	$\overline{BE3:0}$	3	18	ns	
	T_{OV5}, T_{OH5}	$\overline{ADS}$	6	20	ns	
	T_{OV6}, T_{OH6}	W/$\overline{R}$	3	20	ns	
	T_{OV7}, T_{OH7}	D/$\overline{C}$,$\overline{SUP}$,$\overline{DMA}$	4	18	ns	
	T_{OV8}, T_{OH8}	$\overline{BLAST}$, $\overline{WAIT}$	6	18	ns	
	T_{OV9}, T_{OH9}	$\overline{DEN}$	3	18	ns	
	T_{OV10}, T_{OH10}	HOLDA, $\overline{BREQ}$	4	18	ns	
	T_{OV11}, T_{OH11}	$\overline{LOCK}$	4	18	ns	
	T_{OV12}, T_{OH12}	$\overline{DACK3:0}$, EOP3:0/$\overline{TC3:0}$	4	20	ns	
	T_{OV13}, T_{OH13}	D31:0	3	18	ns	
	T_{OV14}, T_{OH14}	DT/$\overline{R}$	T/2 + 3	T/2 + 16	ns	
T_{OF}	Output Float for all outputs		3	22	ns	(6)
	SYNCHRONOUS INPUTS(10)					
T_{IS}	Input Setup					
	T_{IS1}	D31:0	5		ns	(1,11)
	T_{IS2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	9		ns	(1,11)
	T_{IS3}	HOLD	9		ns	(1,11)
T_{IH}	Input Hold					
	T_{IH1}	D31:0	5		ns	(1,11)
	T_{IH2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	7		ns	(1,11)
	T_{IH3}	HOLD	5		ns	(1,11)

4

A.C. Characteristics — 80960CA-25

(80960CA-25 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions**.) (Continued)

Symbol	Parameter	Min	Max	Units	Notes
	RELATIVE OUTPUT TIMINGS(9,7)				
T_{AVSH1}	A31:2 Valid to $\overline{ADS}$ Rising	T − 4	T + 4	ns	
T_{AVSH2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, D/$\overline{C}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{ADS}$ Rising	T − 6	T + 6	ns	
T_{AVEL1}	A31:2 Valid to $\overline{DEN}$ Falling	T − 4	T + 4	ns	
T_{AVEL2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, $\overline{INST}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{DEN}$ Falling	T − 6	T + 6	ns	
T_{NLQV}	$\overline{WAIT}$ Falling to Output Data Valid	±4		ns	
T_{DVNH}	Output Data Valid to $\overline{WAIT}$ Rising	N*T − 4	2N*T + 4	ns	(4)
T_{NLNH}	$\overline{WAIT}$ Falling to $\overline{WAIT}$ Rising	N*T ± 4		ns	(4)
T_{NHQX}	Output Data Hold after $\overline{WAIT}$ Rising	N*T − 4	N*T + 4	ns	(5)
T_{EHQX}	Output Data Hold after $\overline{DEN}$ Rising	− 4	∞	ns	(6)
T_{EHTV}	DT/$\overline{R}$ Hold after $\overline{DEN}$ High	T/2 − 4	∞	ns	(6)
T_{TVEL}	DT/$\overline{R}$ Valid to $\overline{DEN}$ Falling	T/2 − 4	T/2 + 4	ns	(7)
T_{DTS}	Outputs Valid to Tristate	T/2	T/2 + 10	ns	(7)
T_{TSD}	Tristate to Outputs Valid	T/2	T/2 + 10	ns	(7)
	RELATIVE INPUT TIMINGS(7)				
T_{IS4}	$\overline{RESET}$ Input Setup	8		ns	(7)
T_{IH4}	$\overline{RESET}$ Input Hold	7		ns	(7)
T_{IS5}	$\overline{DREQ3:0}$ Input Setup	14		ns	(7)
T_{IH5}	$\overline{DREQ3:0}$ Input Hold	9		ns	(7)

NOTES:
(1) See **Section 4.5.3, A.C. Timing Waveforms** for waveforms and definitions.
(2) See Figure 20 for capacitive derating information for output delays and hold times.
(3) See Figure 21 for capacitive derating information for rise and fall times.
(4) Where N is the number of wait states that are inserted by the Bus Controller Region Table. When there are no wait states in an access, $\overline{WAIT}$ never goes active.
(5) N = Number of wait states inserted with $\overline{READY}$.
(6) Output Data and/or DT/$\overline{R}$ may be driven indefinitely following a cycle if there is no subsequent bus activity.
(7) See Notes 1, 2, and 3.
(8) Since asynchronous inputs are synchronized internally by the 80960CA they have no required setup or hold times in order to be recognized and for proper operation. However, in order to guarantee recognition of the input at a particular rising edge of PCLK2:1 the setup times shown must be met. Asynchronous inputs must be active for at least two consecutive PCLK2:1 rising edges to be seen by the processor.
(9) These specifications are guaranteed by the processor.
(10) These specifications must be met by the system for proper operation of the processor.
(11) This timing is dependent upon the loading of PCLK2:1. Use the derating curves of **Section 4.5.3** to adjust the timing for PCLK2:1 loading.
(12) In the One-x input clock mode the maximum input clock period is limited to 125 ns while the processor is operating. When the processor is in reset, the input clock may stop even in One-x mode.
(13) When in the One-x input clock mode, these specifications assume a stable input clock with a period variation of less than ±0.1% between adjacent cycles.

A.C. Characteristics — 80960CA-16

(80960CA-16 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions.**) (Continued)

Symbol	Parameter		Min	Max	Units	Notes
	INPUT CLOCK(10)					
T_F	CLKIN Frequency		0	32	MHz	(1)
T_C	CLKIN Period	In One-X Mode (f_{CLK1x})	62.5	125	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	31.25	∞	ns	(1)
T_{CS}	CLKIN Period Stability	In One-X Mode (f_{CLK1x})		±0.1%	Δ	(1,13)
T_{CH}	CLKIN High Time	In One-X Mode (f_{CLK1x})	10	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	10	∞	ns	(1)
T_{CL}	CLKIN Low Time	In One-X Mode (f_{CLK1x})	10	62.5	ns	(1,12)
		In Two-X Mode (f_{CLK2x})	10	∞	ns	(1)
T_{CR}	CLKIN Rise Time		0	6	ns	(1)
T_{CF}	CLKIN Fall Time		0	6	ns	(1)
	OUTPUT CLOCKS(9)					
T_{CP}	CLKIN to PCLK2:1 Delay	In One-X Mode (f_{CLK1x})	−2	2	ns	(1,3,13)
		In Two-X Mode (f_{CLK2x})	2	25	ns	(1,3)
T	PCLK2:1 Period	In One-X Mode (f_{CLK1x})	T_C		ns	(1,13)
		In Two-X Mode (f_{CLK2x})	$2T_C$		ns	(1,3)
T_{PH}	PCLK2:1 High Time		(T/2) − 4	T/2	ns	(1,13)
T_{PL}	PCLK2:1 Low Time		(T/2) − 4	T/2	ns	(1,13)
T_{PR}	PCLK2:1 Rise Time		1	4	ns	(1,3)
T_{PF}	PCLK2:1 Fall Time		1	4	ns	(1,3)
	SYNCHRONOUS OUTPUTS(9)					
T_{OV} T_{OH}	Output Valid Delay, Output Hold					(6, 11)
	T_{OV1}, T_{OH1}	A31:28	3	18	ns	
	T_{OV2}, T_{OH2}	A27:4	3	18	ns	
	T_{OV3}, T_{OH3}	A3:2	3	18	ns	
	T_{OV4}, T_{OH4}	$\overline{BE3:0}$	3	20	ns	
	T_{OV5}, T_{OH5}	$\overline{ADS}$	6	22	ns	
	T_{OV6}, T_{OH6}	W/$\overline{R}$	3	22	ns	
	T_{OV7}, T_{OH7}	D/$\overline{C}$,$\overline{SUP}$,$\overline{DMA}$	4	20	ns	
	T_{OV8}, T_{OH8}	$\overline{BLAST}$, $\overline{WAIT}$	6	20	ns	
	T_{OV9}, T_{OH9}	$\overline{DEN}$	3	20	ns	
	T_{OV10}, T_{OH10}	HOLDA, BREQ	4	20	ns	
	T_{OV11}, T_{OH11}	$\overline{LOCK}$	4	20	ns	
	T_{OV12}, T_{OH12}	$\overline{DACK3:0}$, EOP3:0/$\overline{TC3:0}$	4	22	ns	
	T_{OV13}, T_{OH13}	D31:0	3	20	ns	
	T_{OV14}, T_{OH14}	DT/$\overline{R}$	T/2 + 3	T/2 + 18	ns	
T_{OF}	Output Float for all outputs		3	22	ns	(6)
	SYNCHRONOUS INPUTS(10)					
T_{IS}	Input Setup					
	T_{IS1}	D31:0	5		ns	(1,11)
	T_{IS2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	9		ns	(1,11)
	T_{IS3}	HOLD	9		ns	(1,11)
T_{IH}	Input Hold					
	T_{IH1}	D31:0	5		ns	(1,11)
	T_{IH2}	$\overline{BOFF}$, $\overline{READY}$, $\overline{BTERM}$	9		ns	(1,11)
	T_{IH3}	HOLD	7		ns	(1,11)

4

A.C. Characteristics — 80960CA-16

(80960CA-16 only, under the conditions described in **Section 4.2, Operating Conditions** and **Section 4.5.2, A.C. Test Conditions**.) (Continued)

Symbol	Parameter	Min	Max	Units	Notes
	RELATIVE OUTPUT TIMINGS(9,7)				
T_{AVSH1}	A31:2 Valid to $\overline{ADS}$ Rising	T − 4	T + 4	ns	
T_{AVSH2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, D/$\overline{C}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{ADS}$ Rising	T − 6	T + 6	ns	
T_{AVEL1}	A31:2 Valid to $\overline{DEN}$ Falling	T − 6	T + 6	ns	
T_{AVEL2}	$\overline{BE3:0}$, W/$\overline{R}$, $\overline{SUP}$, $\overline{INST}$, $\overline{DMA}$, $\overline{DACK3:0}$ Valid to $\overline{DEN}$ Falling	T − 6	T + 6	ns	
T_{NLQV}	$\overline{WAIT}$ Falling to Output Data Valid	±4		ns	
T_{DVNH}	Output Data Valid to $\overline{WAIT}$ Rising	N*T − 4	2N*T + 4	ns	(4)
T_{NLNH}	$\overline{WAIT}$ Falling to $\overline{WAIT}$ Rising	N*T ± 4		ns	(4)
T_{NHQX}	Output Data Hold after $\overline{WAIT}$ Rising	N*T − 4	N*T + 4	ns	(5)
T_{EHQX}	Output Data Hold after $\overline{DEN}$ Rising	− 6	∞	ns	(6)
T_{EHTV}	DT/$\overline{R}$ Hold after $\overline{DEN}$ High	T/2 − 4	∞	ns	(6)
T_{TVEL}	DT/$\overline{R}$ Valid to $\overline{DEN}$ Falling	T/2 − 4	T/2 + 4	ns	(7)
T_{DTS}	Outputs Valid to Tristate	T/2	T/2 + 10	ns	(7)
T_{TSD}	Tristate to Outputs Valid	T/2	T/2 + 10	ns	(7)
	RELATIVE INPUT TIMINGS(7)				
T_{IS4}	$\overline{RESET}$ Input Setup	10		ns	(8)
T_{IH4}	$\overline{RESET}$ Input Hold	9		ns	(8)
T_{IS5}	$\overline{DREQ3:0}$ Input Setup	16		ns	(8)
T_{IH5}	$\overline{DREQ3:0}$ Input Hold	11		ns	(8)

NOTES:
(1) See **Section 4.5.3, A.C. Timing Waveforms** for waveforms and definitions.
(2) See Figure 20 for capacitive derating information for output delays and hold times.
(3) See Figure 21 for capacitive derating information for rise and fall times.
(4) Where N is the number of wait states that are inserted by the Bus Controller Region Table. When there are no wait states in an access, $\overline{WAIT}$ never goes active.
(5) N = Number of wait state inserted with $\overline{READY}$.
(6) Output Data and/or DT/$\overline{R}$ may be driven indefinitely following a cycle if there is no subsequent bus activity.
(7) See Notes 1, 2, and 3.
(8) Since asynchronous inputs are synchronized internally by the 80960CA they have no required setup or hold times in order to be recognized and for proper operation. However, in order to guarantee recognition of the input at a particular rising edge of PCLK2:1 the setup times shown must be met. Asynchronous inputs must be active for at least two consecutive PCLK2:1 rising edges to be seen by the processor.
(9) These specifications are guaranteed by the processor.
(10) These specifications must be met by the system for proper operation of the processor.
(11) This timing is dependent upon the loading of PCLK2:1. Use the derating curves of **Section 4.5.3** to adjust the timing for PCLK2:1 loading.
(12) In the One-x input clock mode the maximum input clock period is limited to 125 ns while the processor is operating. When the processor is in reset, the input clock may stop even in One-x mode.
(13) When in the One-x input clock mode, these specifications assume a stable input clock with a period variation of less than ±0.1% between adjacent cycles.

4.5.2. A.C. TEST CONDITIONS

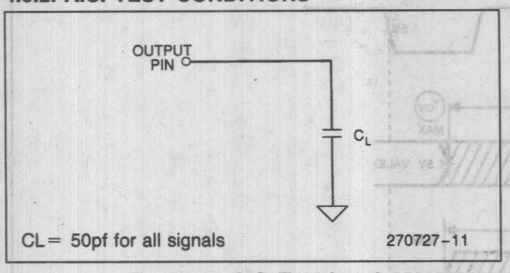


Figure 14. A.C. Test Load

The A.C Specifications in Section 4.5 are tested with the 50 pf load shown in Figure 14. See **Section 4.5.4, Derating Curves**, to see how timings vary with load capacitance.

Specifications are measured at the 1.5V crossing point, unless otherwise indicated. Input waveforms are assumed to have a rise-and-fall time of ≤ 2 ns from 0.8V to 2.0V. See **Section 4.5.3, A.C. Timing Waveforms**, for A.C. spec definitions, test points, and illustrations.

4.5.3. A.C. TIMING WAVEFORMS

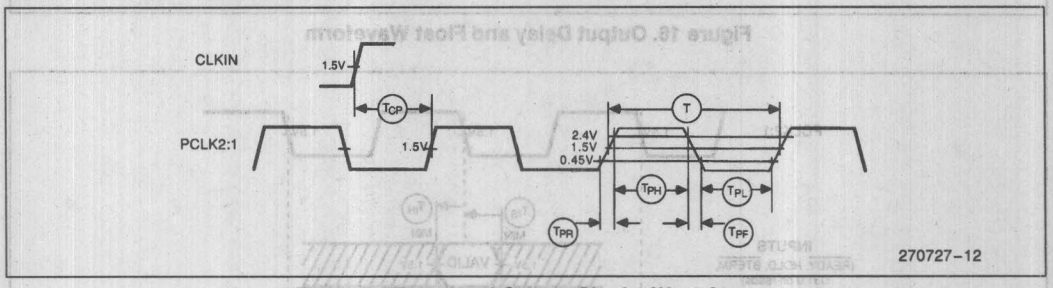


Figure 15. Input and Output Clocks Waveform

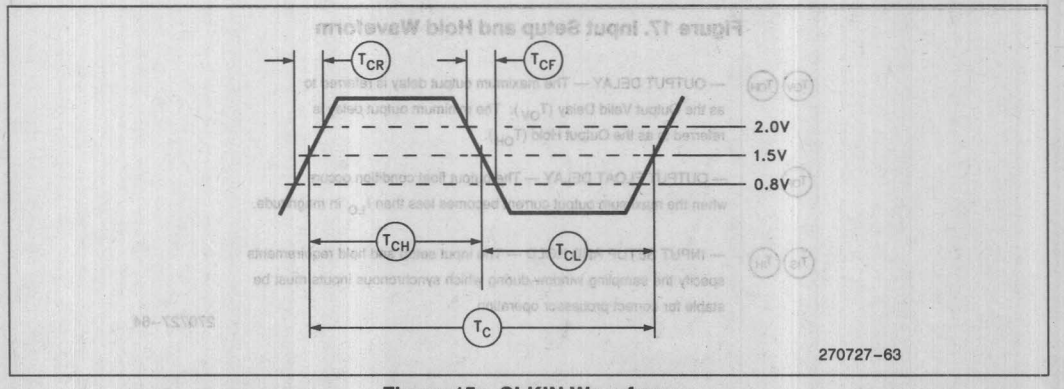


Figure 15a. CLKIN Waveform

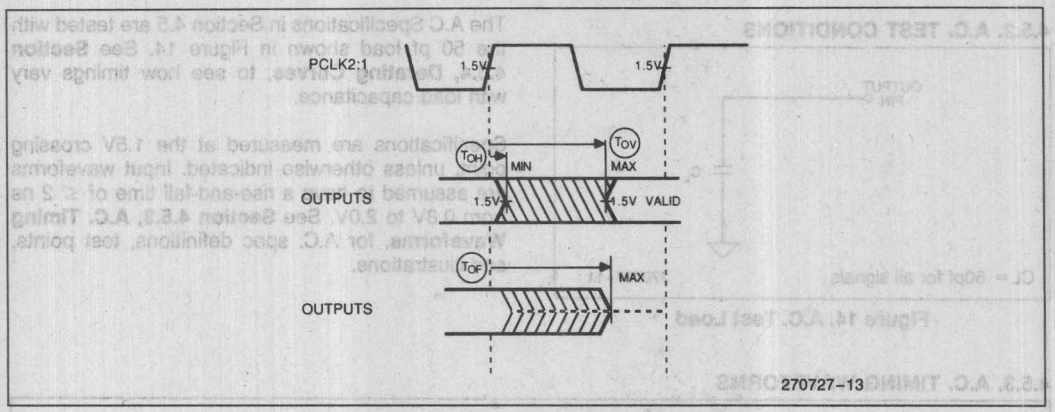


Figure 16. Output Delay and Float Waveform

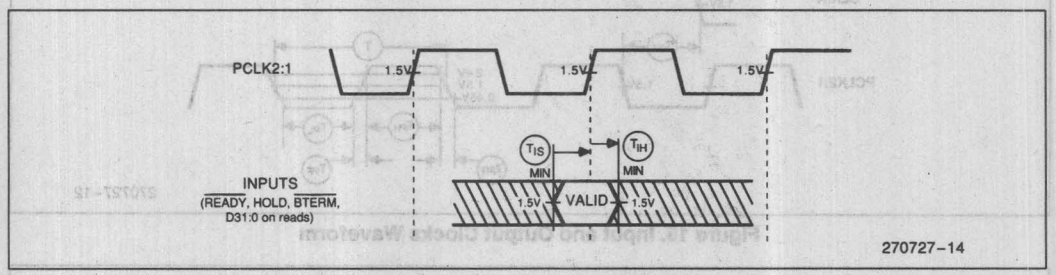


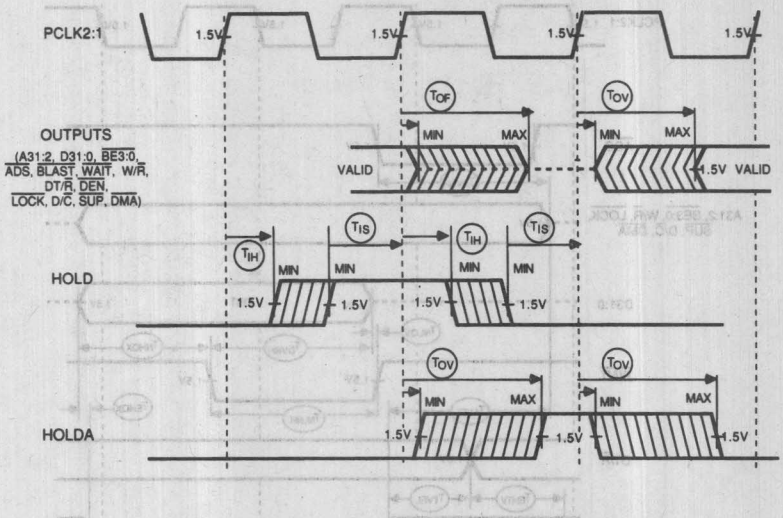
Figure 17. Input Setup and Hold Waveform

(T_{OV}) (T_{OH}) — OUTPUT DELAY — The maximum output delay is referred to as the Output Valid Delay (T_{OV}). The minimum output delay is referred to as the Output Hold (T_{OH}).

(T_{OF}) — OUTPUT FLOAT DELAY — The output float condition occurs when the maximum output current becomes less than I_{LO} in magnitude.

(T_{IS}) (T_{IH}) — INPUT SETUP AND HOLD — The input setup and hold requirements specify the sampling window during which synchronous inputs must be stable for correct processor operation.

270727-64



TOV TOH — OUTPUT DELAY — The maximum output delay is referred to as the Output Valid Delay (T_{OV}). The minimum output delay is referred to as the Output Hold (T_{OH}).

TOF — OUTPUT FLOAT DELAY — The output float condition occurs when the maximum output current becomes less than I_{LO} in magnitude.

TIS TIH — INPUT SETUP AND HOLD — The input setup and hold requirements specify the sampling window during which synchronous inputs must be stable for correct processor operation.

270727-15

Figure 18. Hold Acknowledge Timings

4

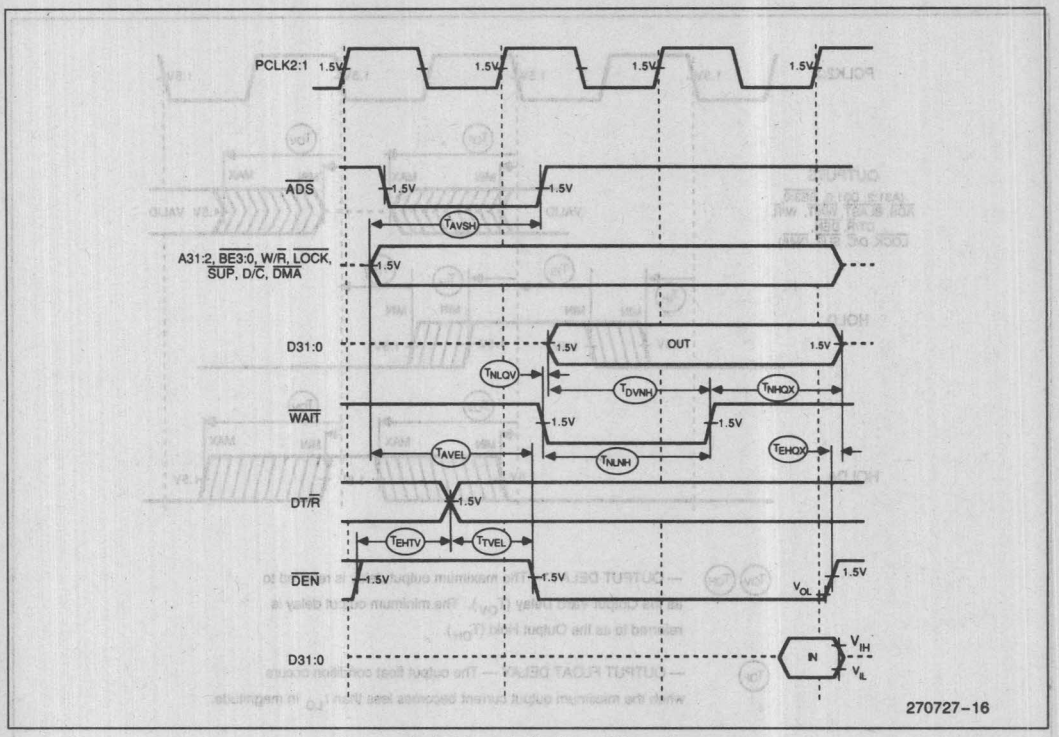
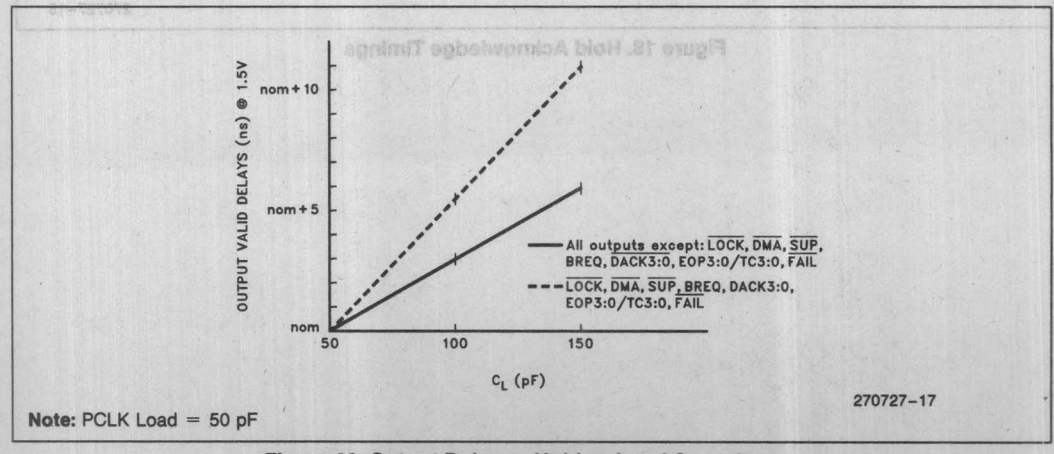


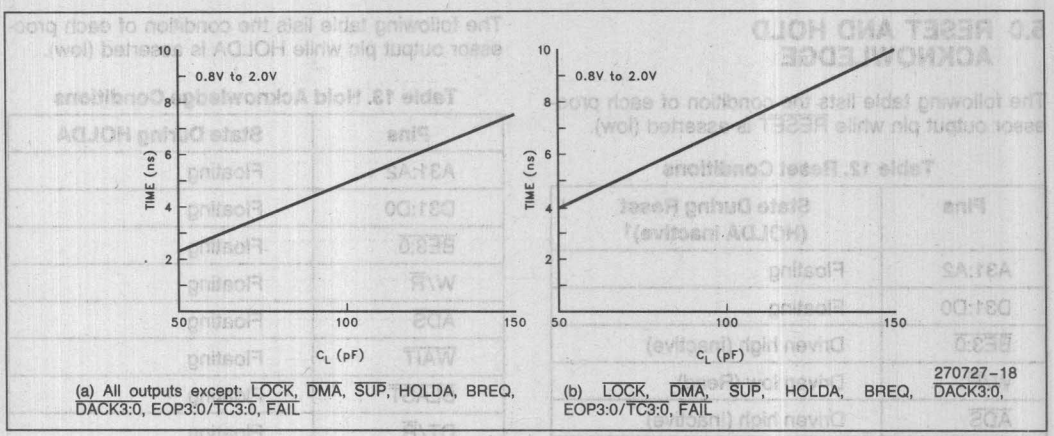
Figure 19. Relative-timings Waveforms

DERATING CURVES



Note: PCLK Load = 50 pF

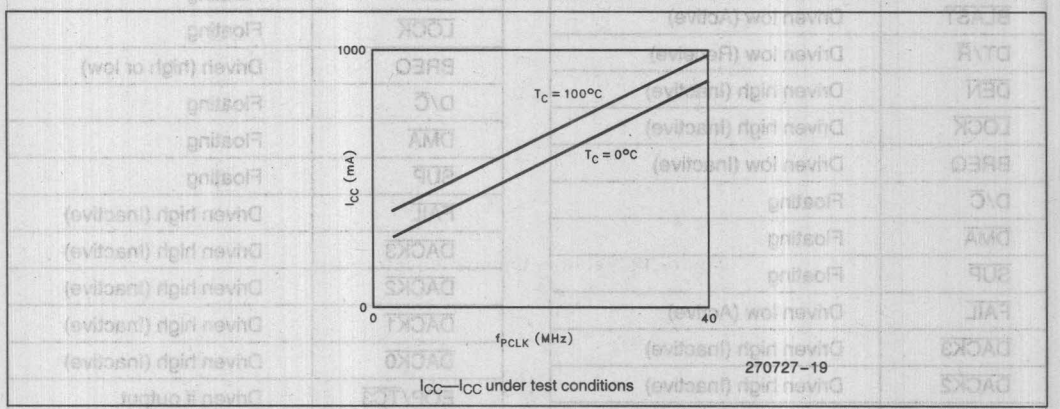
Figure 20. Output Delay or Hold vs Load Capacitance



(a) All outputs except: $\overline{LOCK}$, $\overline{DMA}$, $\overline{SUP}$, HOLDA, BREQ, $\overline{DACK3:0}$, EOP3:0/$\overline{TC3:0}$, $\overline{FAIL}$

(b) $\overline{LOCK}$, $\overline{DMA}$, $\overline{SUP}$, HOLDA, BREQ, $\overline{DACK3:0}$, EOP3:0/$\overline{TC3:0}$, $\overline{FAIL}$

Figure 21. Rise and Fall Time Derating at Highest Operating Temperature and Minimum V_{CC}



I_{CC}—I_{CC} under test conditions

Figure 22. I_{CC} vs Frequency and Temperature

4

5.0 RESET AND HOLD ACKNOWLEDGE

The following table lists the condition of each processor output pin while RESET is asserted (low).

Table 12. Reset Conditions

Pins	State During Reset (HOLDA inactive)[1]
A31:A2	Floating
D31:D0	Floating
BE3:0	Driven high (Inactive)
W/R	Driven low (Read)
ADS	Driven high (Inactive)
WAIT	Driven high (Inactive)
BLAST	Driven low (Active)
DT/R	Driven low (Receive)
DEN	Driven high (Inactive)
LOCK	Driven high (Inactive)
BREQ	Driven low (Inactive)
D/C	Floating
DMA	Floating
SUP	Floating
FAIL	Driven low (Active)
DACK3	Driven high (Inactive)
DACK2	Driven high (Inactive)
DACK1	Driven high (Inactive)
DACK0	Driven high (Inactive)
EOP/TC3	Floating (set to input mode)
EOP/TC2	Floating (set to input mode)
EOP/TC1	Floating (set to input mode)
EOP/TC0	Floating (set to input mode)

NOTE:
(1) With regard to bus output pin state only, the Hold Acknowledge state takes precedence over the reset state. Although asserting the RESET pin will internally reset the processor, the processor's bus output pins will not enter the reset state if it has granted Hold Acknowledge to a previous HOLD request (HOLDA is active). Furthermore, the processor will grant new HOLD requests and enter the Hold Acknowledge state even while in reset.
For example, if HOLDA is not active and the processor is in the reset state, then HOLD is asserted, the processor's bus pins will enter the Hold Acknowledge state and *HOLDA will be granted. The processor will not be able to* perform memory accesses until the HOLD request is removed, even if the RESET pin is brought high. This operation is provided to simplify boot-up synchronization among multiple processors sharing the same bus.

The following table lists the condition of each processor output pin while HOLDA is asserted (low).

Table 13. Hold Acknowledge Conditions

Pins	State During HOLDA
A31:A2	Floating
D31:D0	Floating
BE3:0	Floating
W/R	Floating
ADS	Floating
WAIT	Floating
BLAST	Floating
DT/R	Floating
DEN	Floating
LOCK	Floating
BREQ	Driven (high or low)
D/C	Floating
DMA	Floating
SUP	Floating
FAIL	Driven high (Inactive)
DACK3	Driven high (Inactive)
DACK2	Driven high (Inactive)
DACK1	Driven high (Inactive)
DACK0	Driven high (Inactive)
EOP/TC3	Driven if output
EOP/TC2	Driven if output
EOP/TC1	Driven if output
EOP/TC0	Driven if output

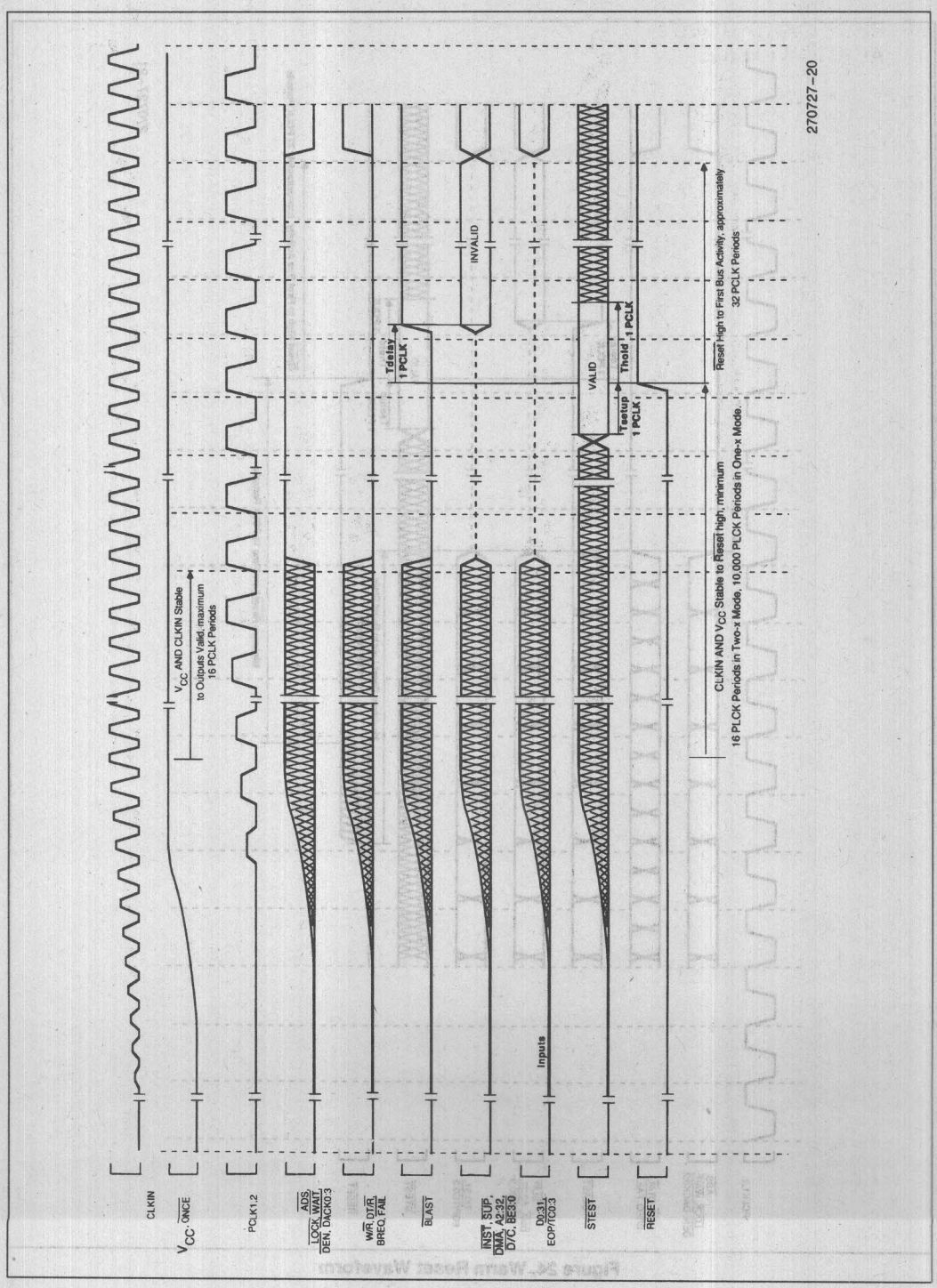


Figure 23. Cold Reset Waveform

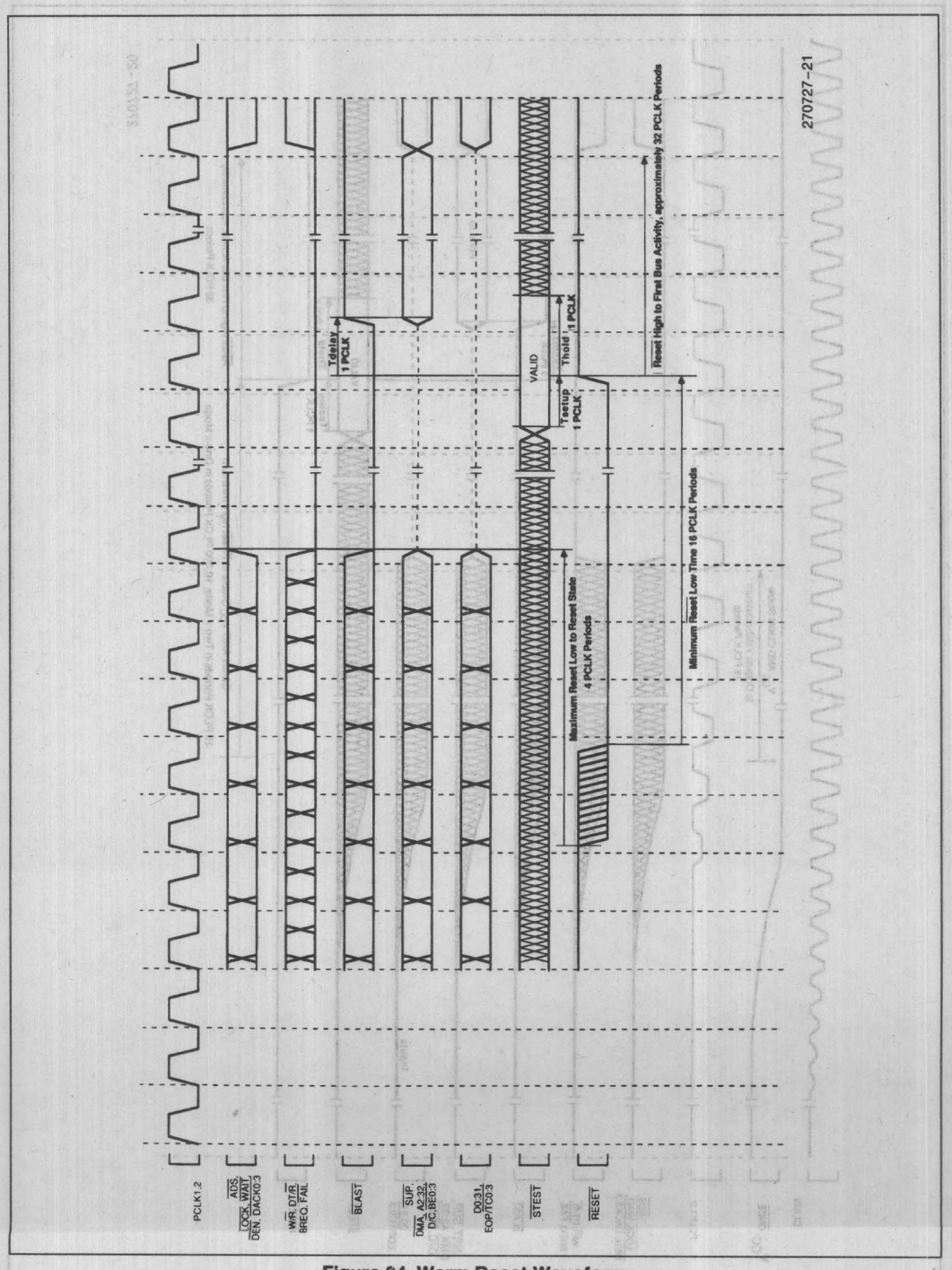


Figure 24. Warm Reset Waveform

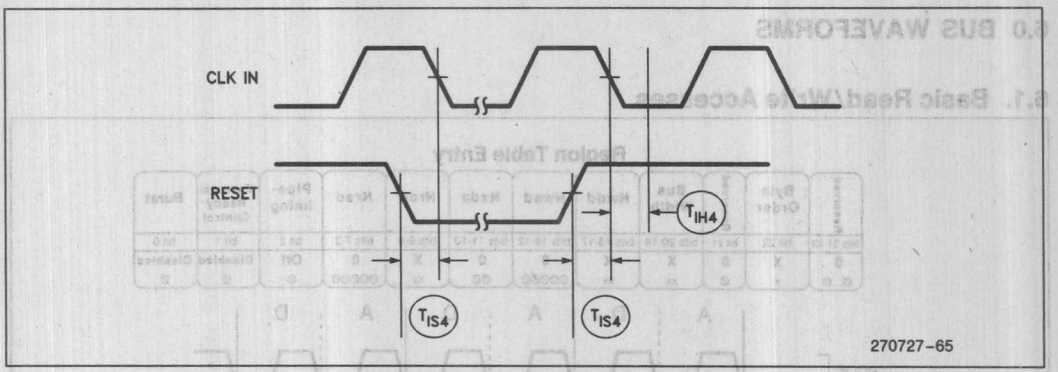


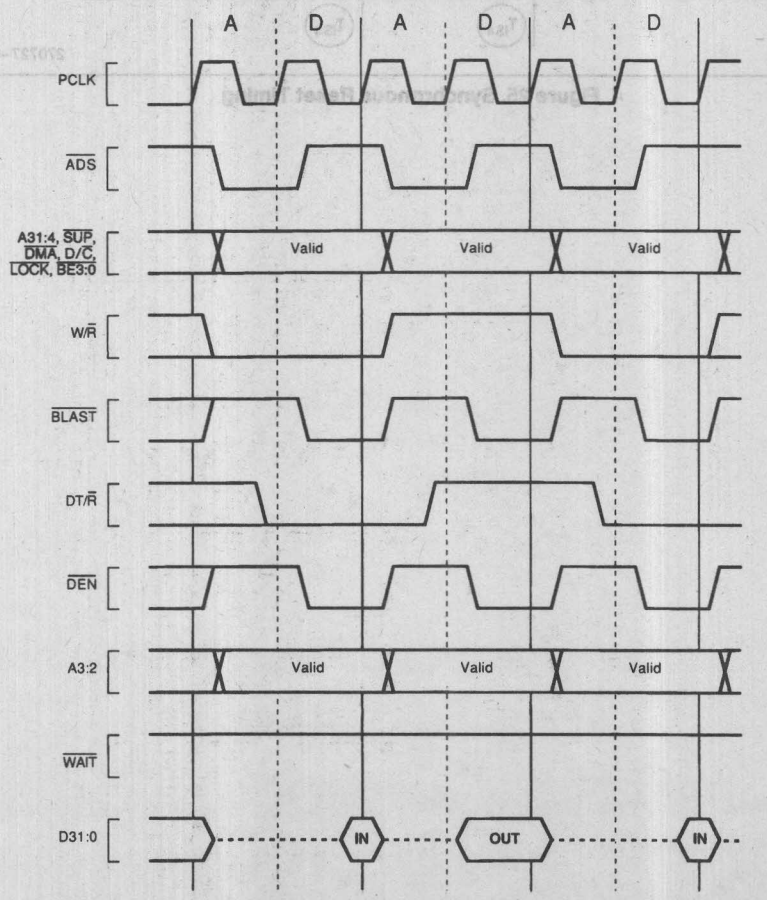
Figure 25. Synchronous Reset Timing

6.0 BUS WAVEFORMS

6.1. Basic Read/Write Accesses

Region Table Entry

Reserved	Byte Order	Reserved	Bus Width	Nwdd	Nwad	Nxda	Nrdd	Nrad	Pipe-lining	External Ready Control	Burst
bits 31-23	bit 22	bit 21	bits 20-19	bits 18-17	bits 16-12	bits 11-10	bits 9-8	bits 7-3	bit 2	bit 1	bit 0
0 Ø...Ø	X x	0 Ø	X xx	X xx	0 ØØØØØ	0 ØØ	X xx	0 ØØØØØ	Off Ø	Disabled Ø	Disabled Ø



270727-26

Figure 26. Non-Burst, Non-Pipelined Accesses without wait states

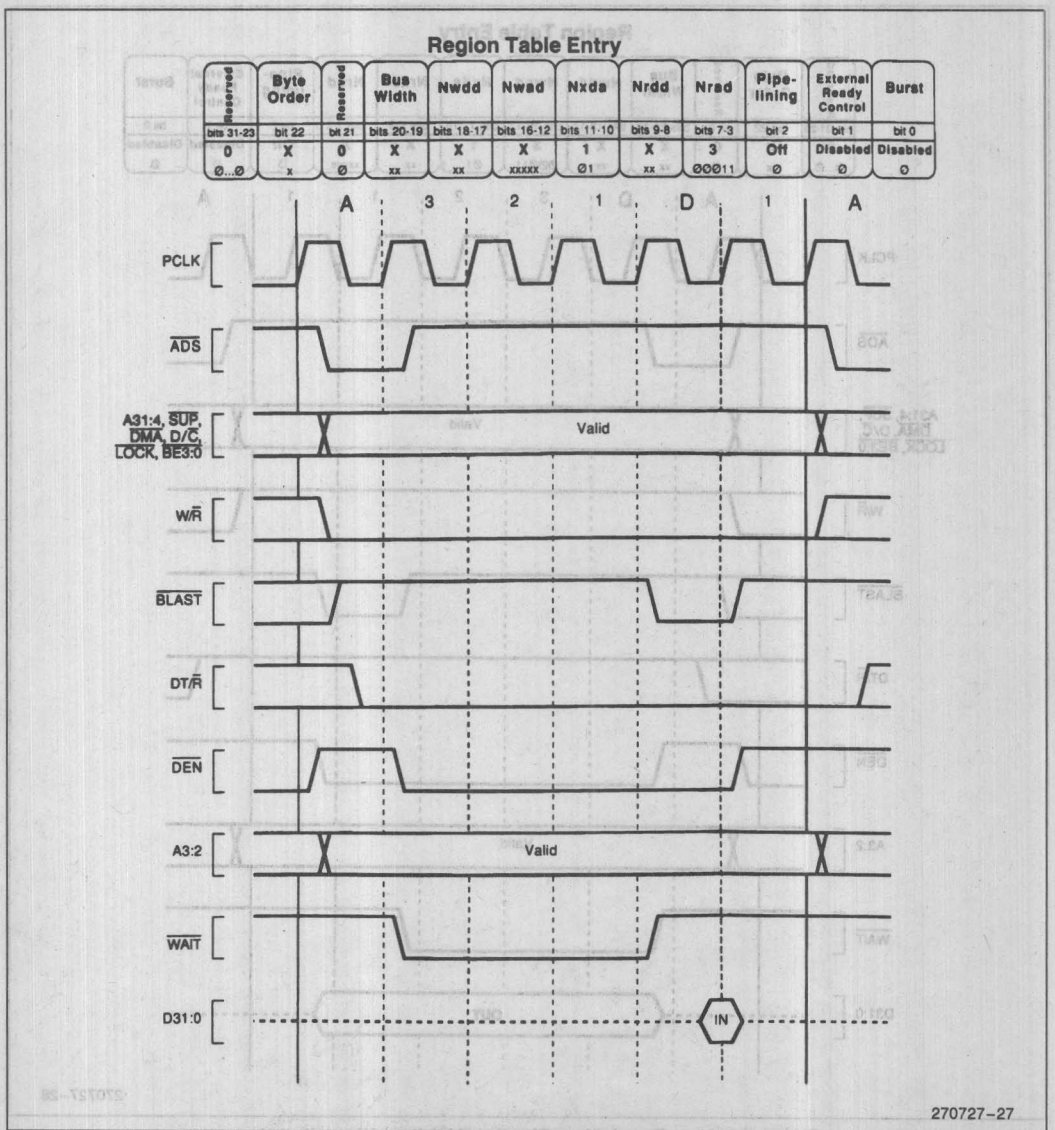
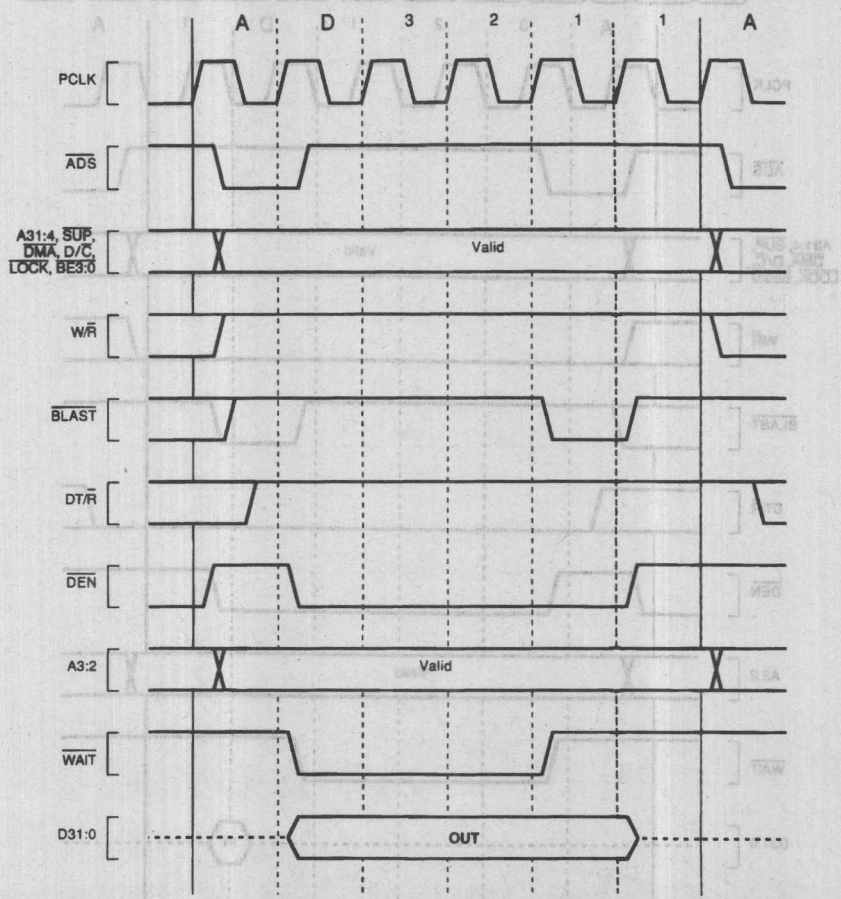


Figure 27. Non-Burst, Non-Pipelined Read with wait states

Region Table Entry

Reserved	Byte Order	Reserved	Bus Width	Nwdd	Nwad	Nxda	Nrdd	Nrad	Pipe-lining	External Ready Control	Burst
bits 31-23	bit 22	bit 21	bits 20-19	bits 18-17	bits 16-12	bits 11-10	bits 9-8	bits 7-3	bit 2	bit 1	bit 0
0	X	0	X	X	3	1	X	X	Off	Disabled	Disabled
Ø..Ø	x	Ø	xx	xx	ØØØ11	Ø1	xx	xxxxx	Ø	Ø	Ø



270727-28

Figure 28. Non-Burst, Non-Pipelined Write with wait states

6.2. Burst Accesses

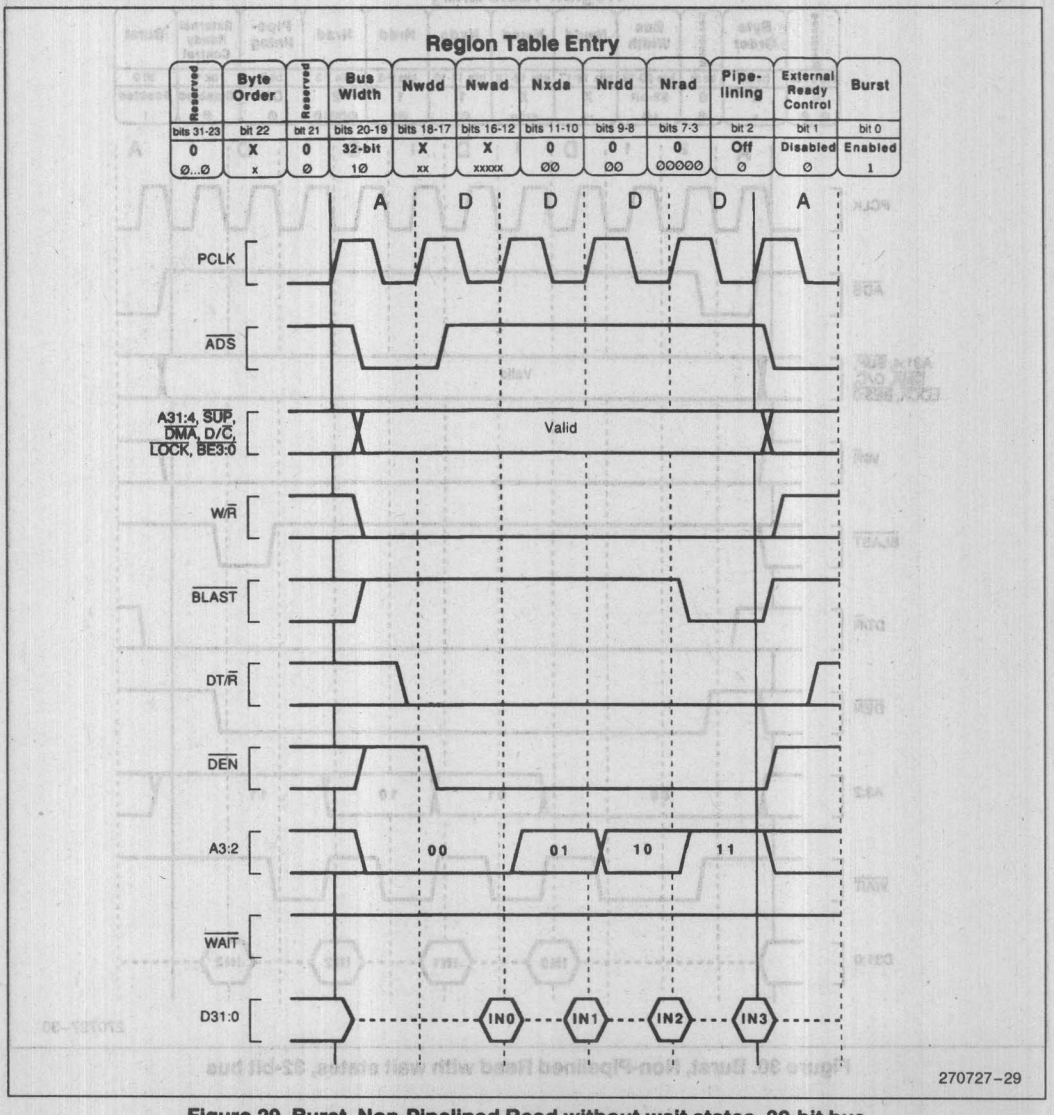


Figure 29. Burst, Non-Pipelined Read without wait states, 32-bit bus

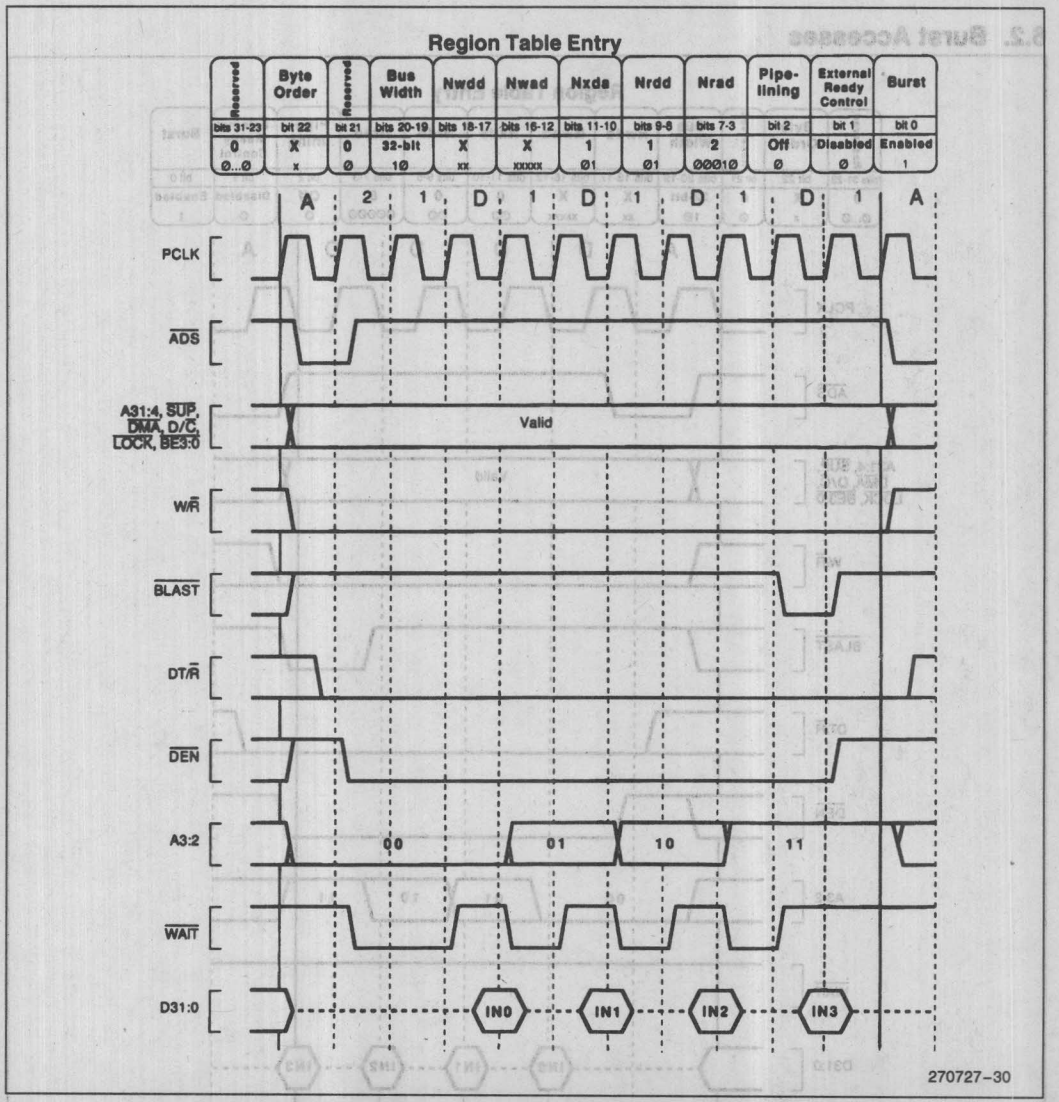
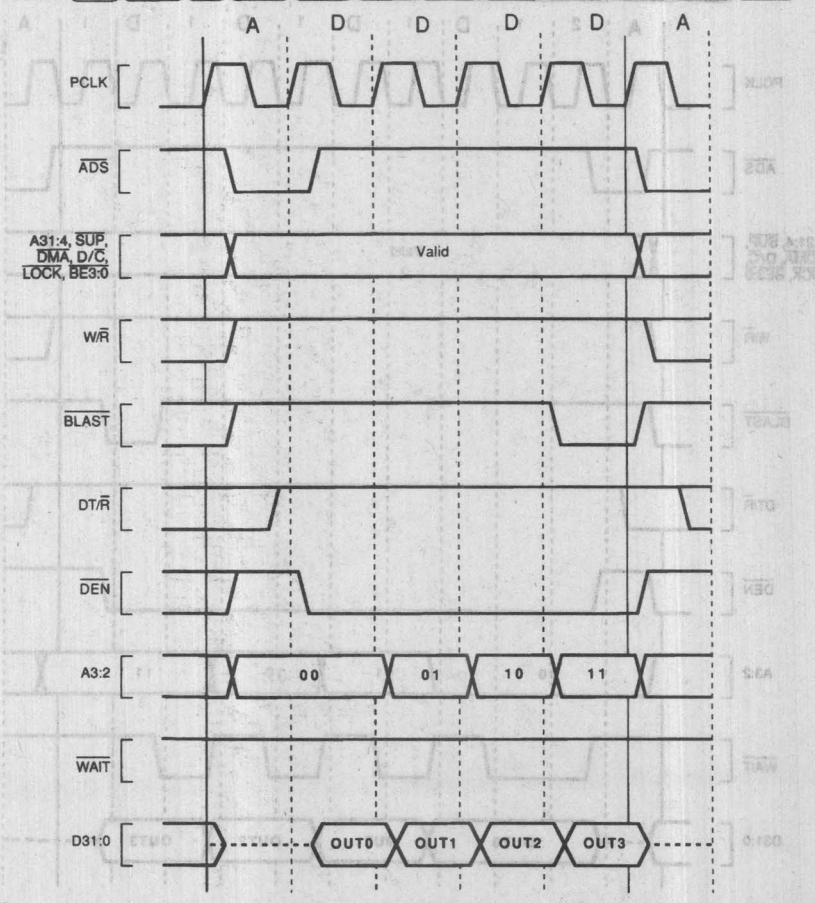


Figure 30. Burst, Non-Pipelined Read with wait states, 32-bit bus

Region Table Entry

Reserved	Byte Order	Reserved	Bus Width	Nwdd	Nwad	Nxda	Nrdd	Nrad	Pipe-lining	External Ready Control	Burst
bits 31-23	bit 22	bit 21	bits 20-19	bits 18-17	bits 16-12	bits 11-10	bits 9-8	bits 7-3	bit 2	bit 1	bit 0
0 Ø...Ø	X x	0 Ø	32-bit 1Ø	0 ØØ	0 ØØØØØ	0 ØØ	X xx	X xxxxx	Off Ø	Disabled Ø	Enabled 1



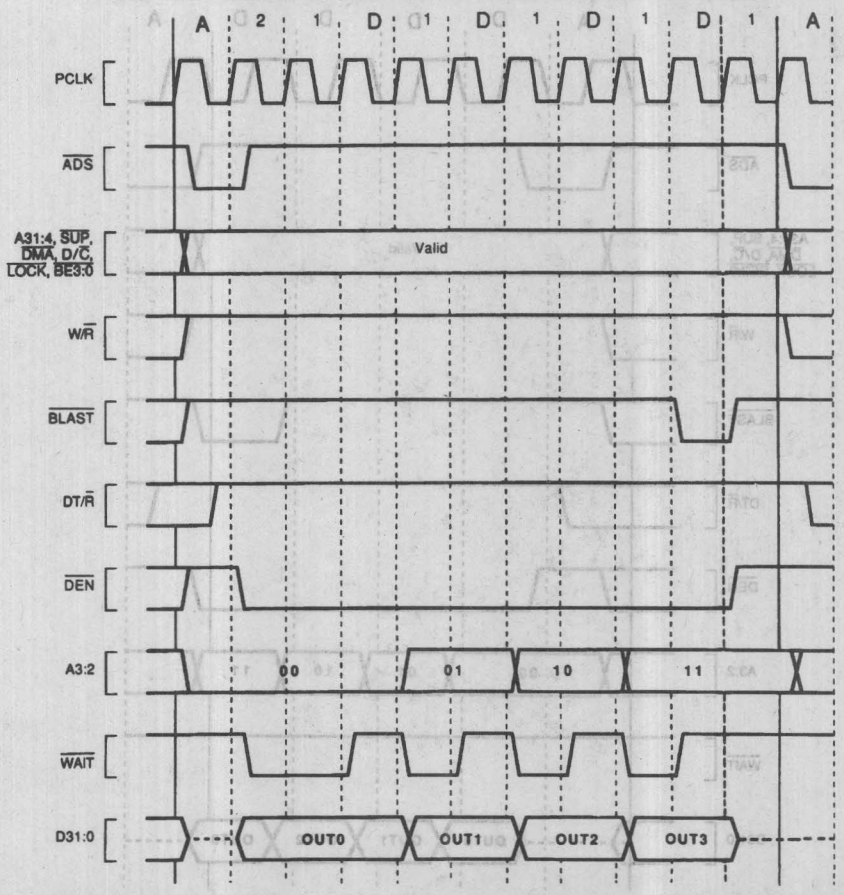
270727-31

Figure 31. Burst, Non-Pipelined Write without wait states, 32-bit bus

4

Region Table Entry

Reserved	Byte Order	Reserved	Bus Width	Nwdd	Nwad	Nxda	Nrdd	Nrad	Pipe-lining	External Ready Control	Burst
bits 31-23	bit 22	bit 21	bits 20-19	bits 18-17	bits 16-12	bits 11-10	bits 9-8	bits 7-3	bit 2	bit 1	bit 0
0	X	0	32-bit	1	3	1	X	X	Off	Disabled	Enabled
Ø...Ø	x	Ø	1Ø	Ø1	ØØØ11	Ø1	xx	xxxxx	Ø	Ø	1



270727-32

Figure 32. Burst, Non-Pipelined Write with wait states, 32-bit bus

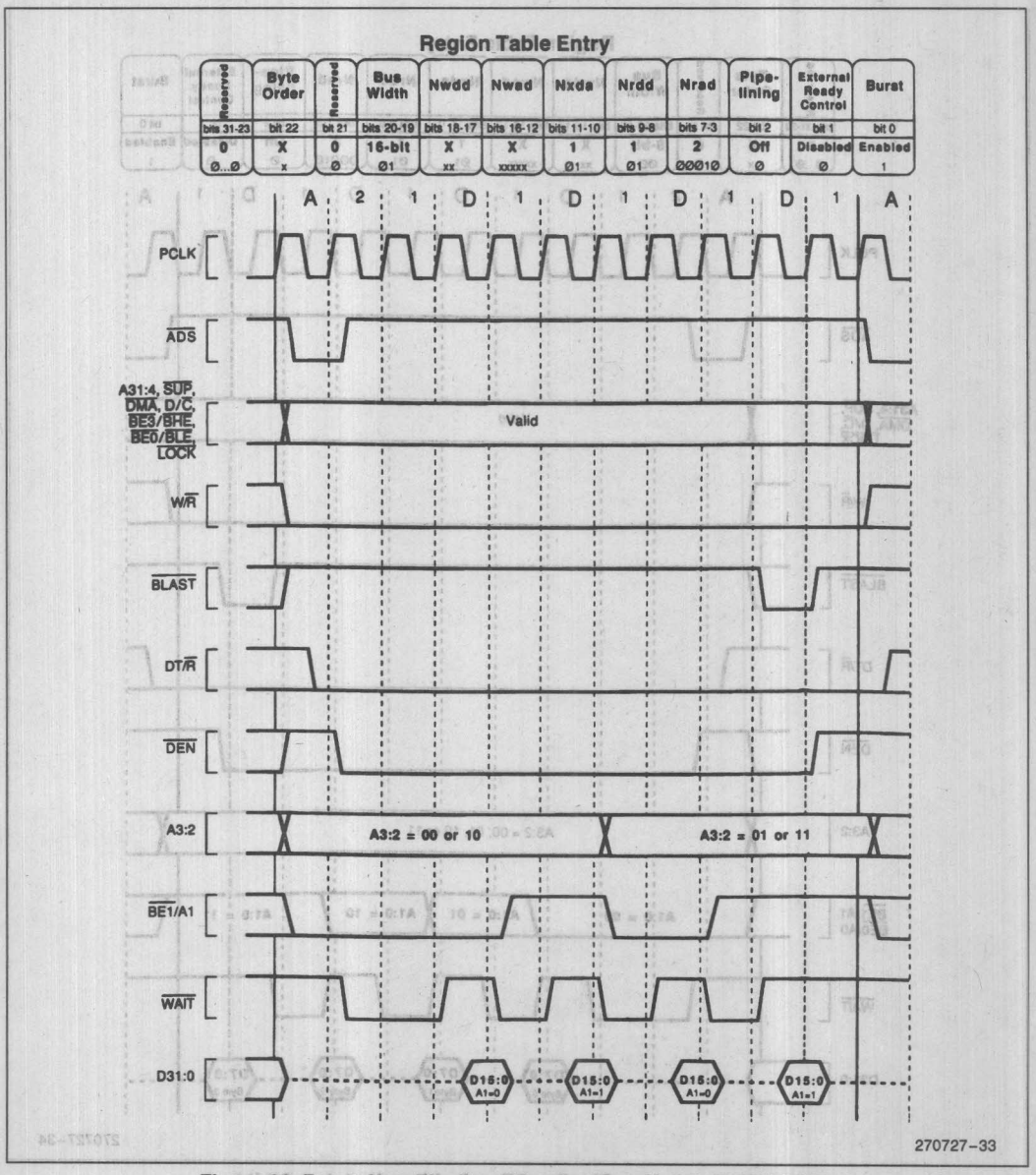


Figure 33. Burst, Non-Pipelined Read with wait states, 16-bit bus

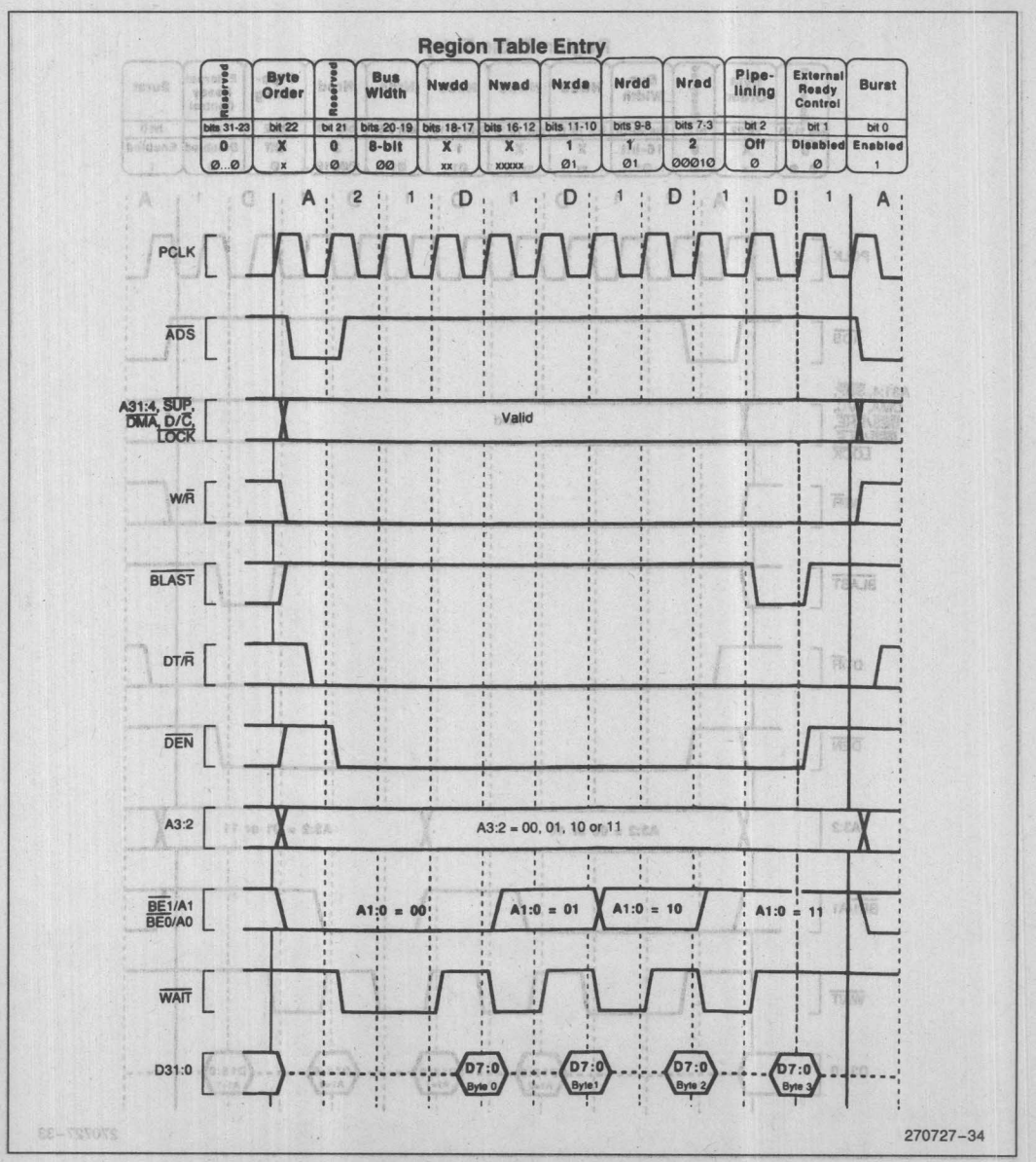


Figure 34. Burst, Non-Pipelined Read with wait states, 8-bit bus

6.3. Pipelined Accesses

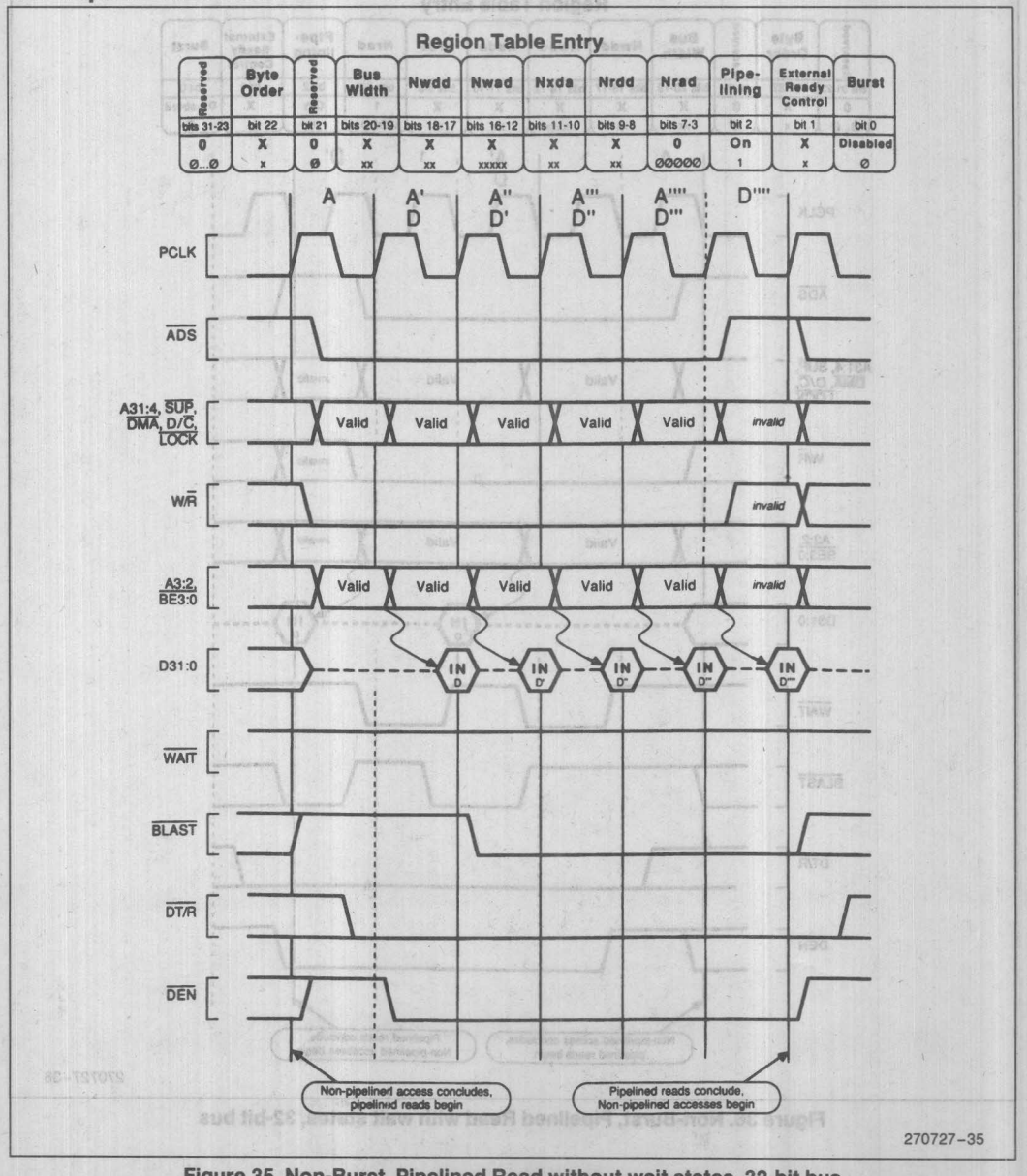
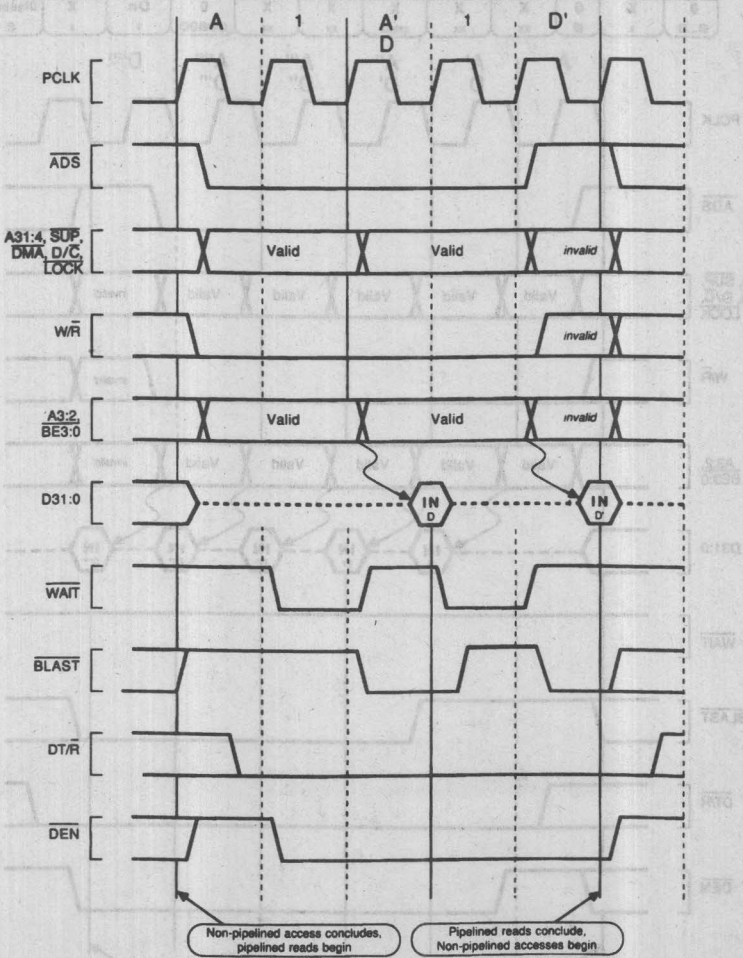


Figure 35. Non-Burst, Pipelined Read without wait states, 32-bit bus

Region Table Entry

Reserved	Byte Order	Reserved	Bus Width	Nwdd	Nwad	Nxda	Nrdd	Nrad	Pipe-lining	External Ready Control	Burst
bits 31-23	bit 22	bit 21	bits 20-19	bits 18-17	bits 16-12	bits 11-10	bits 9-8	bits 7-3	bit 2	bit 1	bit 0
0	X	0	X	X	X	X	X	1	On	X	Disabled
Ø...Ø	x	Ø	xx	xx	xxxxx	xx	xx	ØØØØ1	1	x	Ø



270727-36

Figure 36. Non-Burst, Pipelined Read with wait states, 32-bit bus

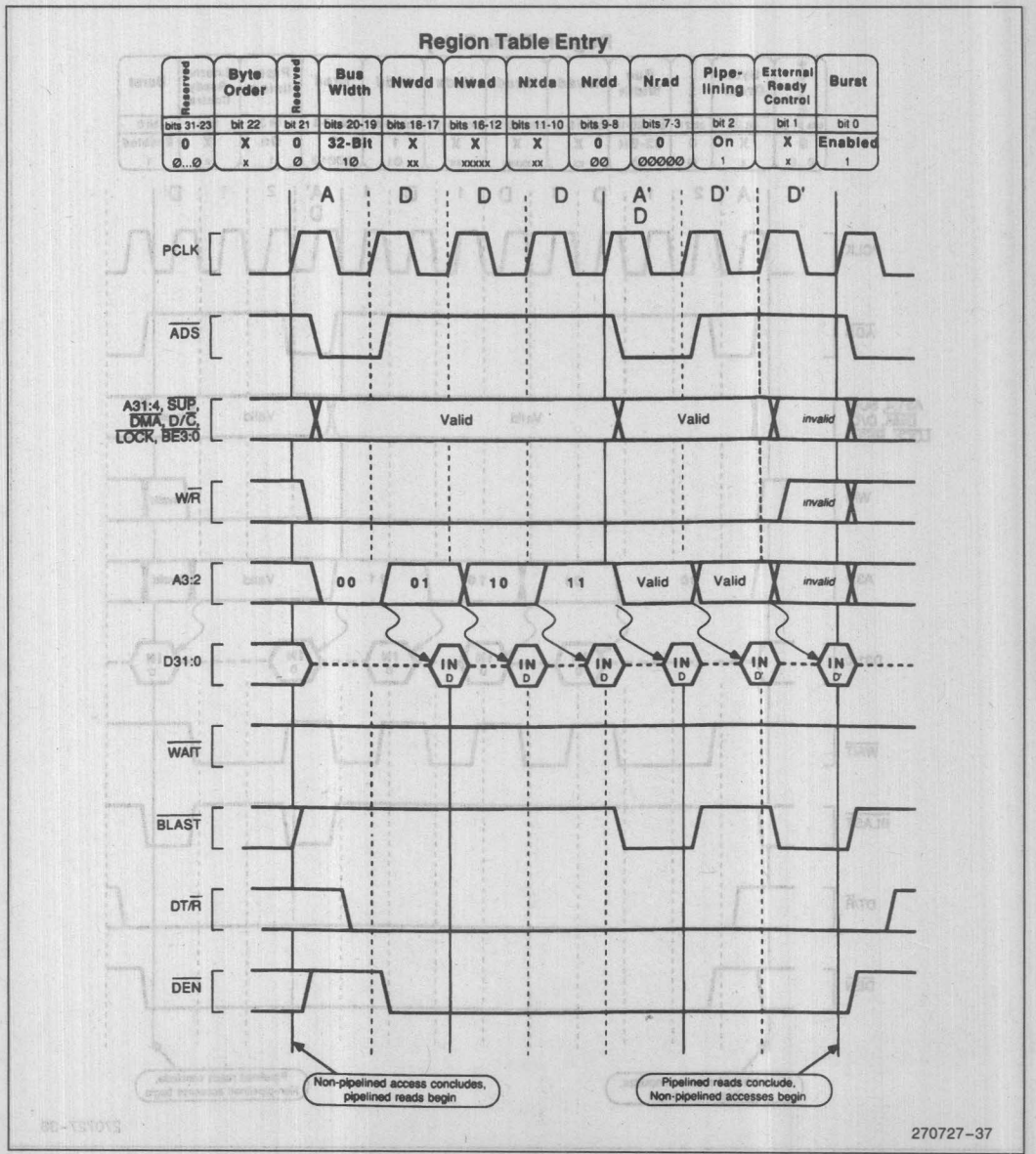


Figure 37. Burst, Pipelined Read without wait states, 32-bit bus

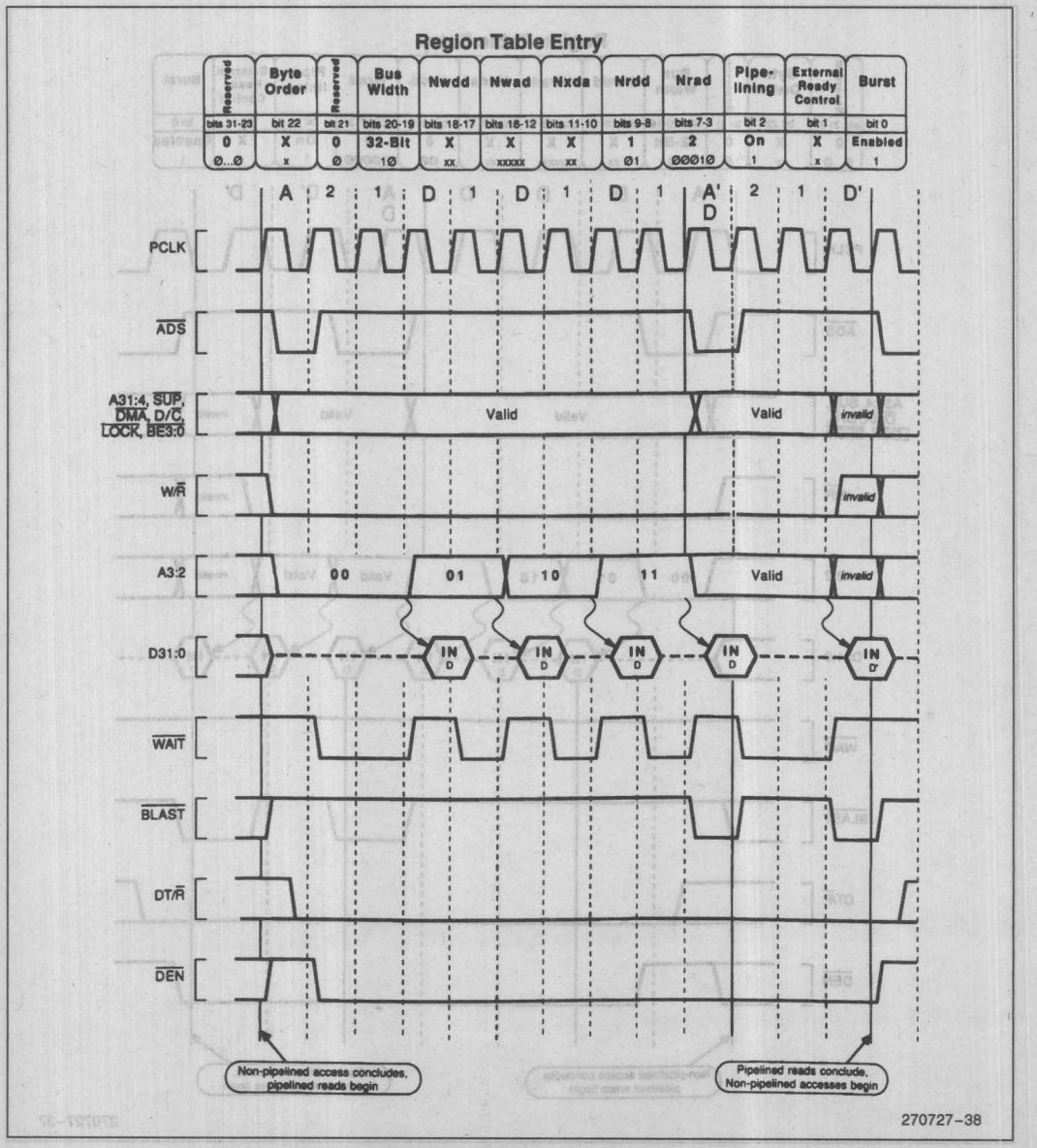


Figure 38. Burst, Pipelined Read with wait states, 32-bit bus

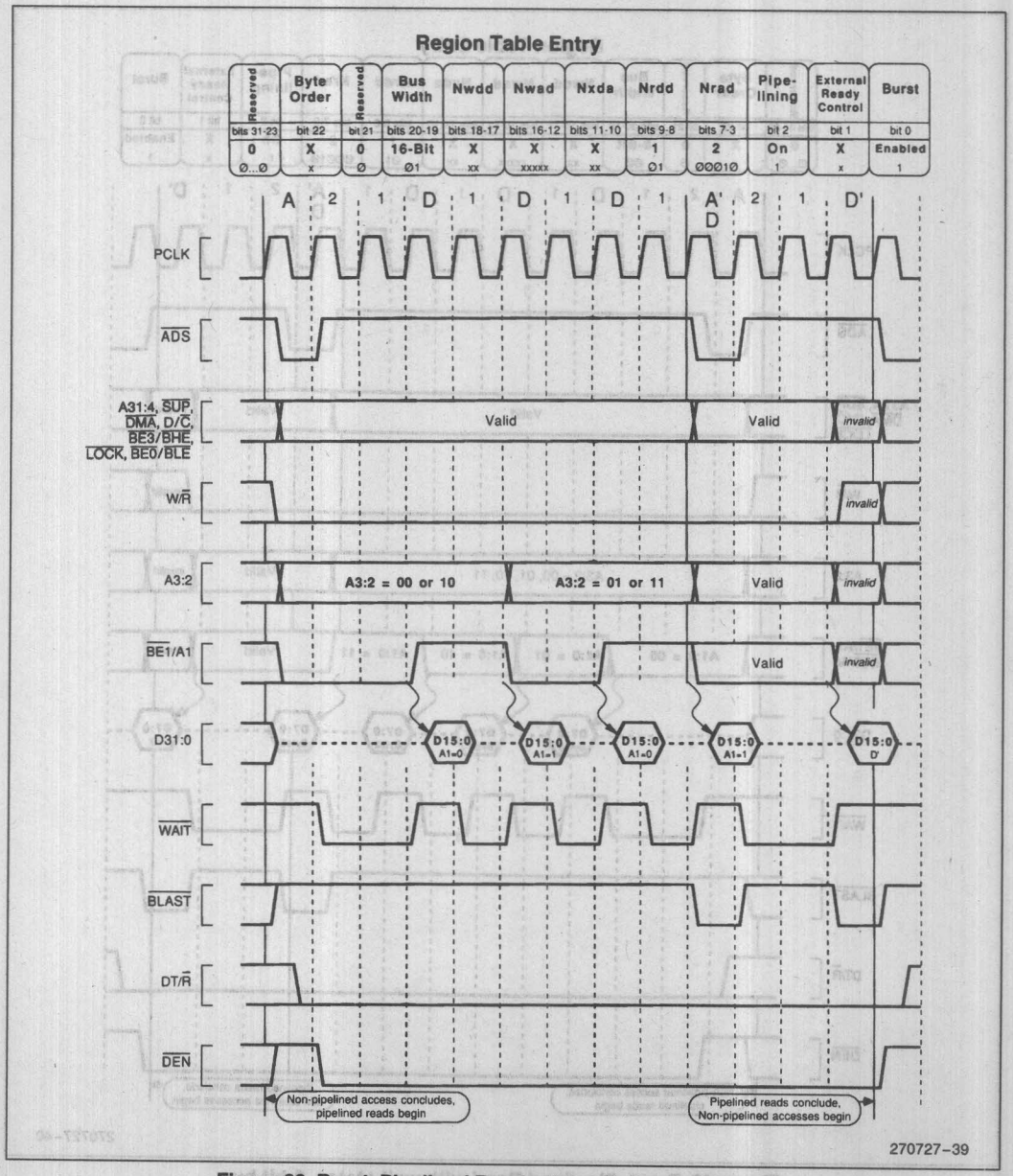


Figure 39. Burst, Pipelined Read with wait states, 16-bit bus

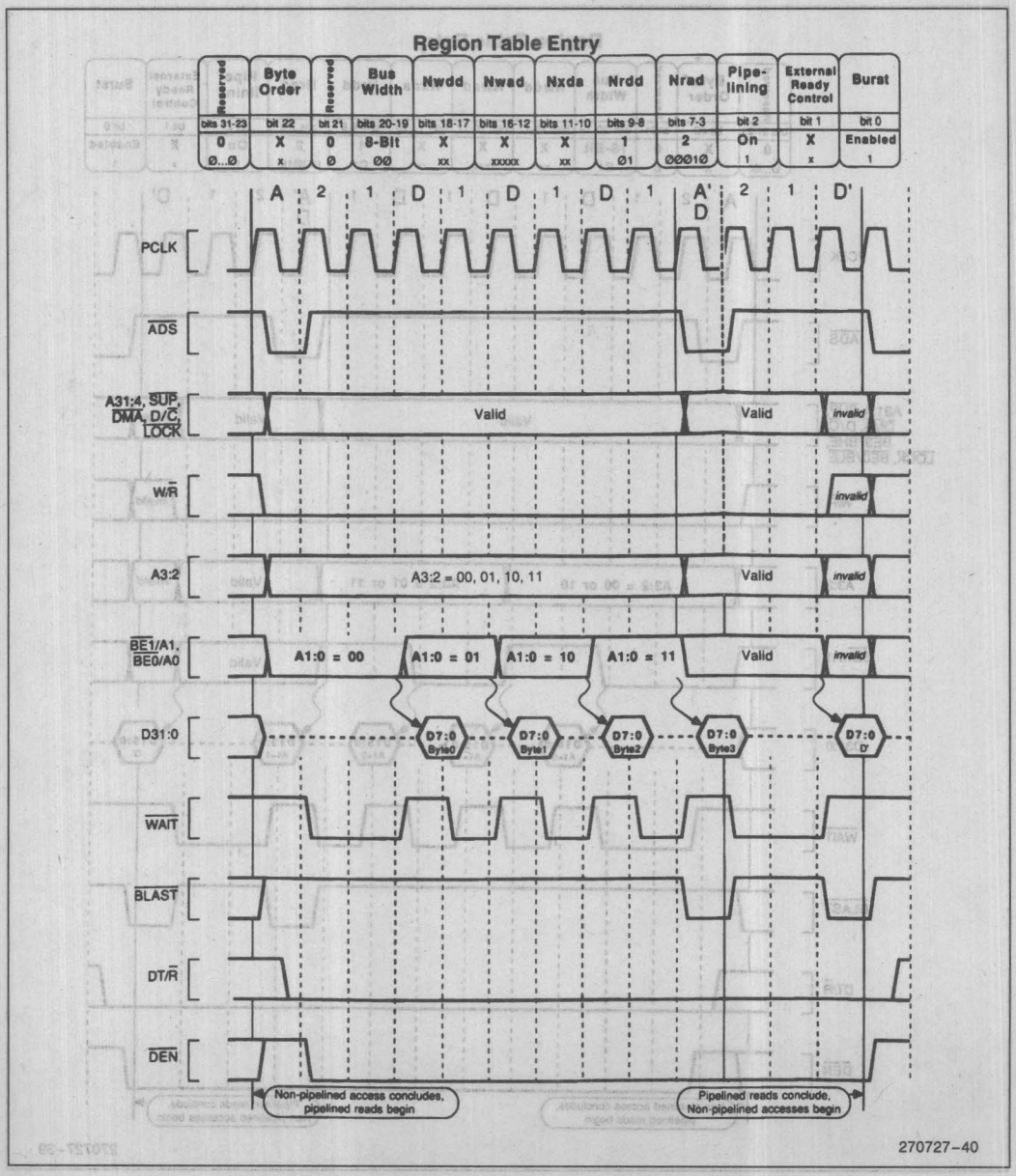


Figure 40. Burst, Pipelined Read with wait states, 8-bit bus

6.4. Using $\overline{\text{READY}}$

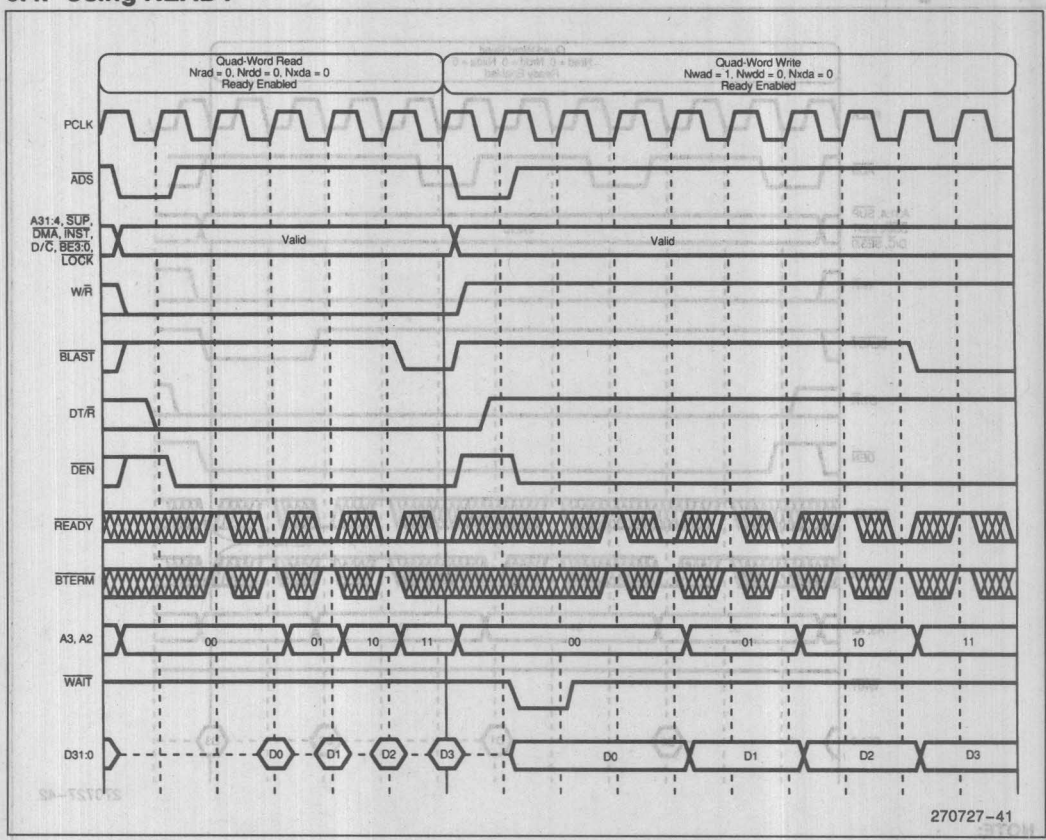
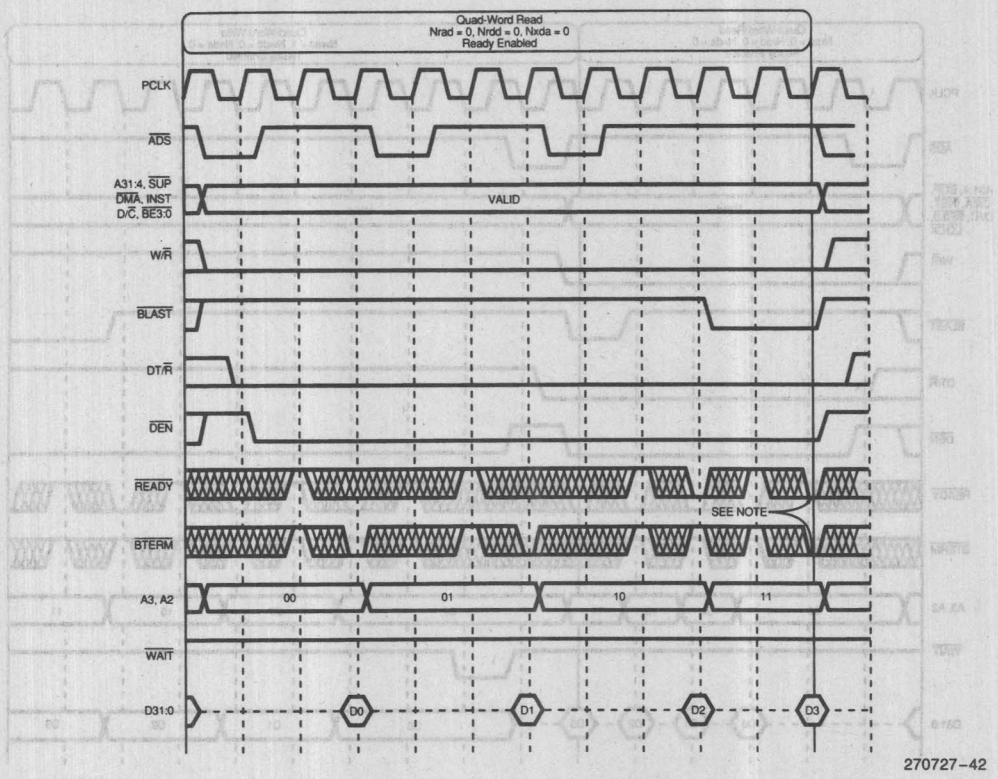


Figure 41. Using External $\overline{\text{READY}}$

6.5. Using $\overline{\text{BTERM}}$



NOTE:
$\overline{\text{READY}}$ adds memory access time to data transfers, whether or not the bus access is a burst access. $\overline{\text{BTERM}}$ interrupts a bus access, whether or not the bus access has more data transfers pending. Either the $\overline{\text{READY}}$ signal or the $\overline{\text{BTERM}}$ signal will terminate a bus access if the signal is asserted during the last (or only) data transfer of the bus access.

Figure 42. Terminating a Burst with $\overline{\text{BTERM}}$

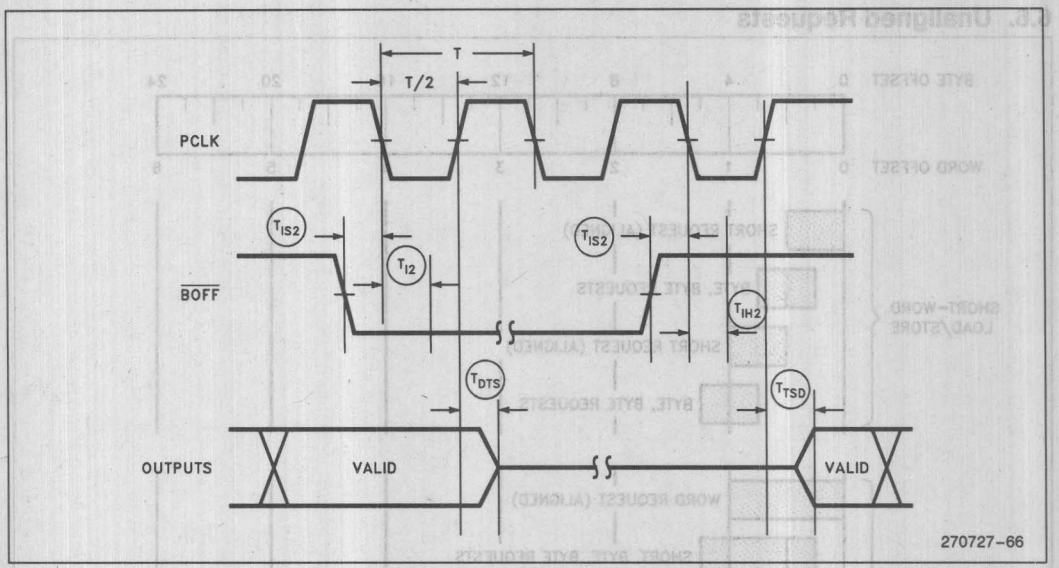


Figure 43. BOFF Input Timing

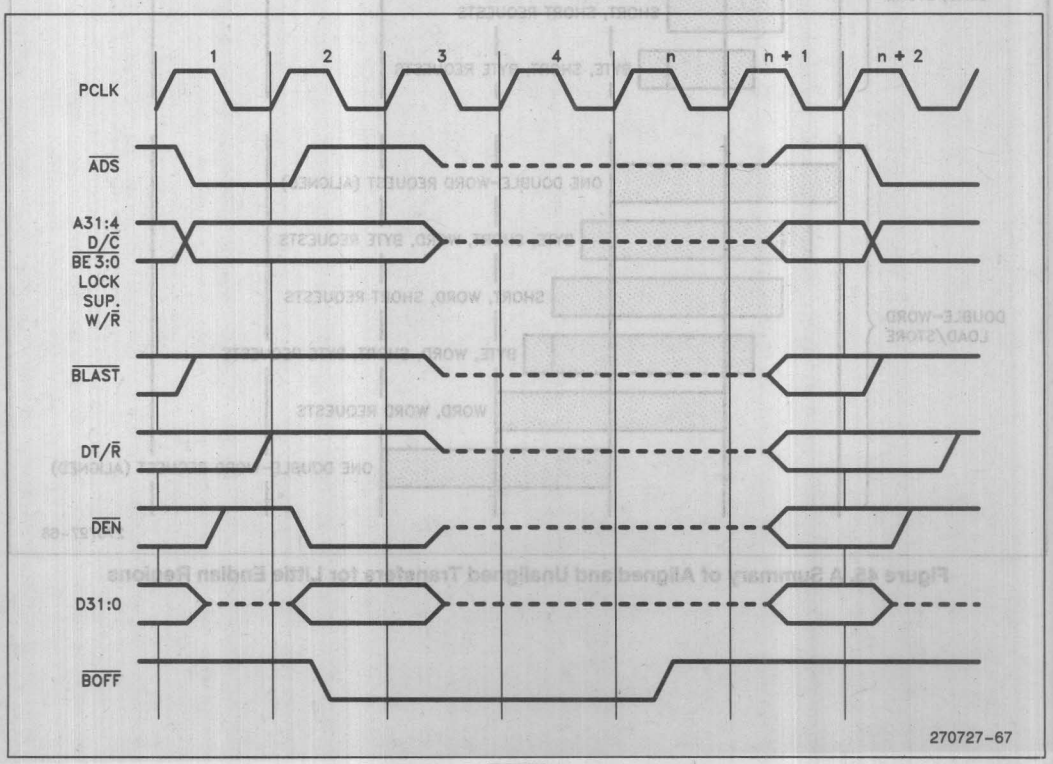


Figure 44. BOFF Bus Timing

6.6. Unaligned Requests

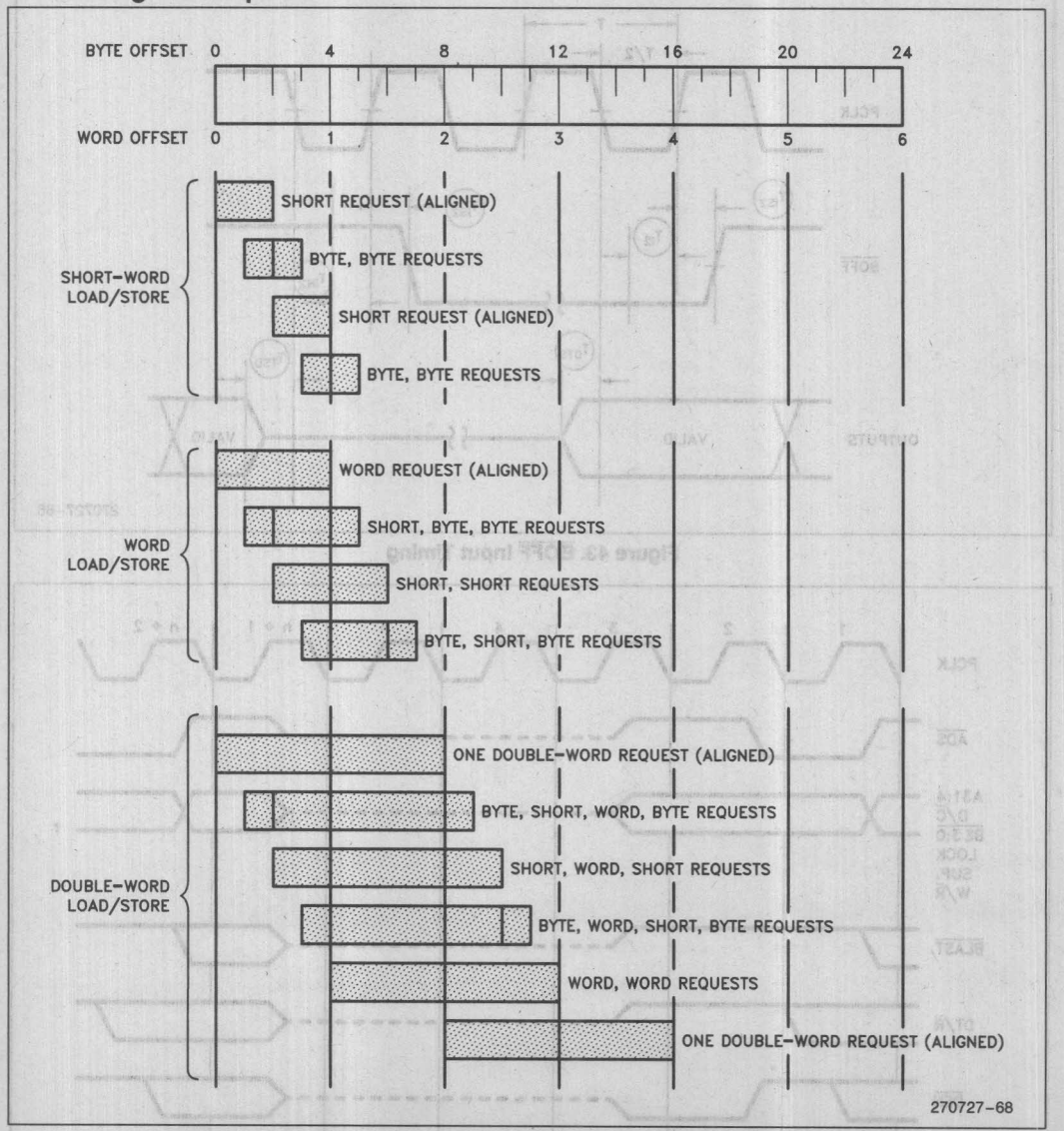


Figure 45. A Summary of Aligned and Unaligned Transfers for Little Endian Regions

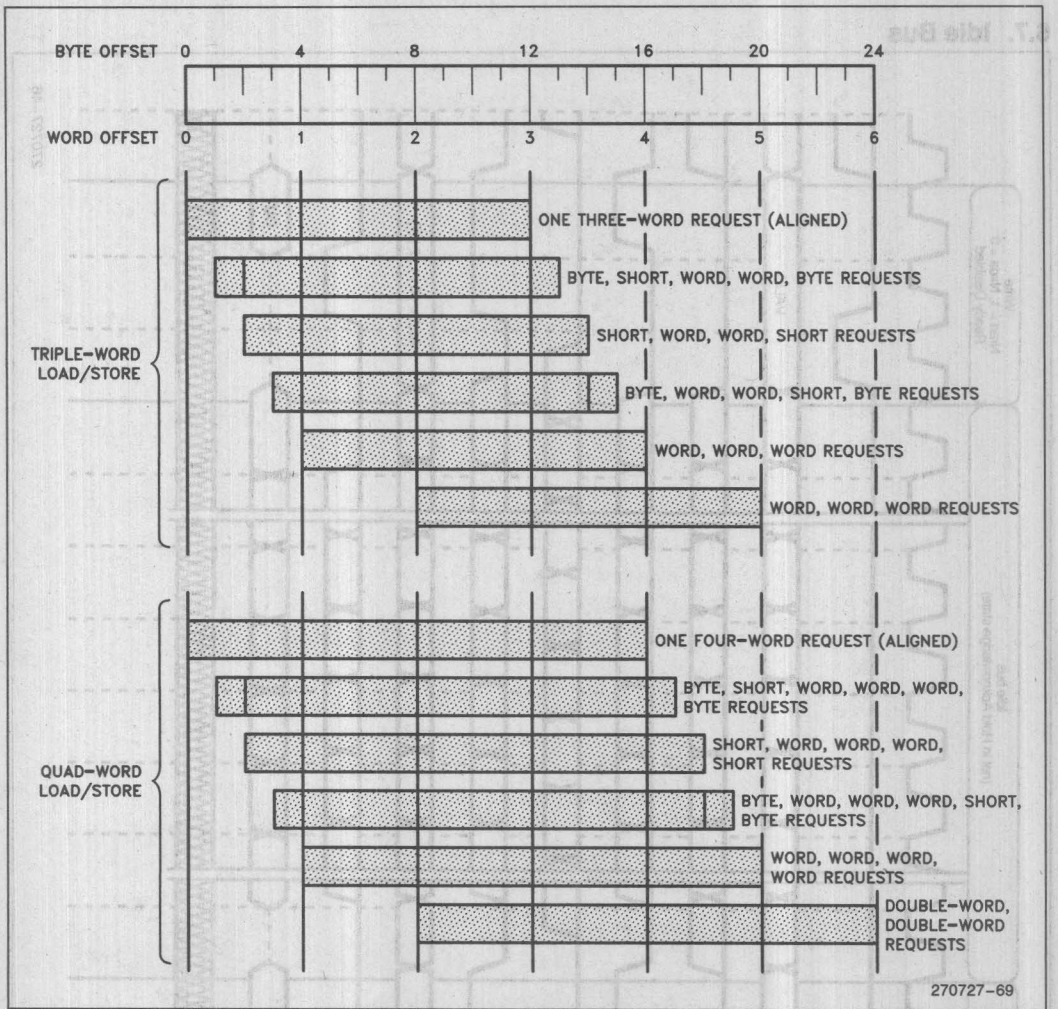


Figure 46. A Summary of Aligned and Unaligned Transfers for Little Endian Regions (Continued)

6.7. Idle Bus

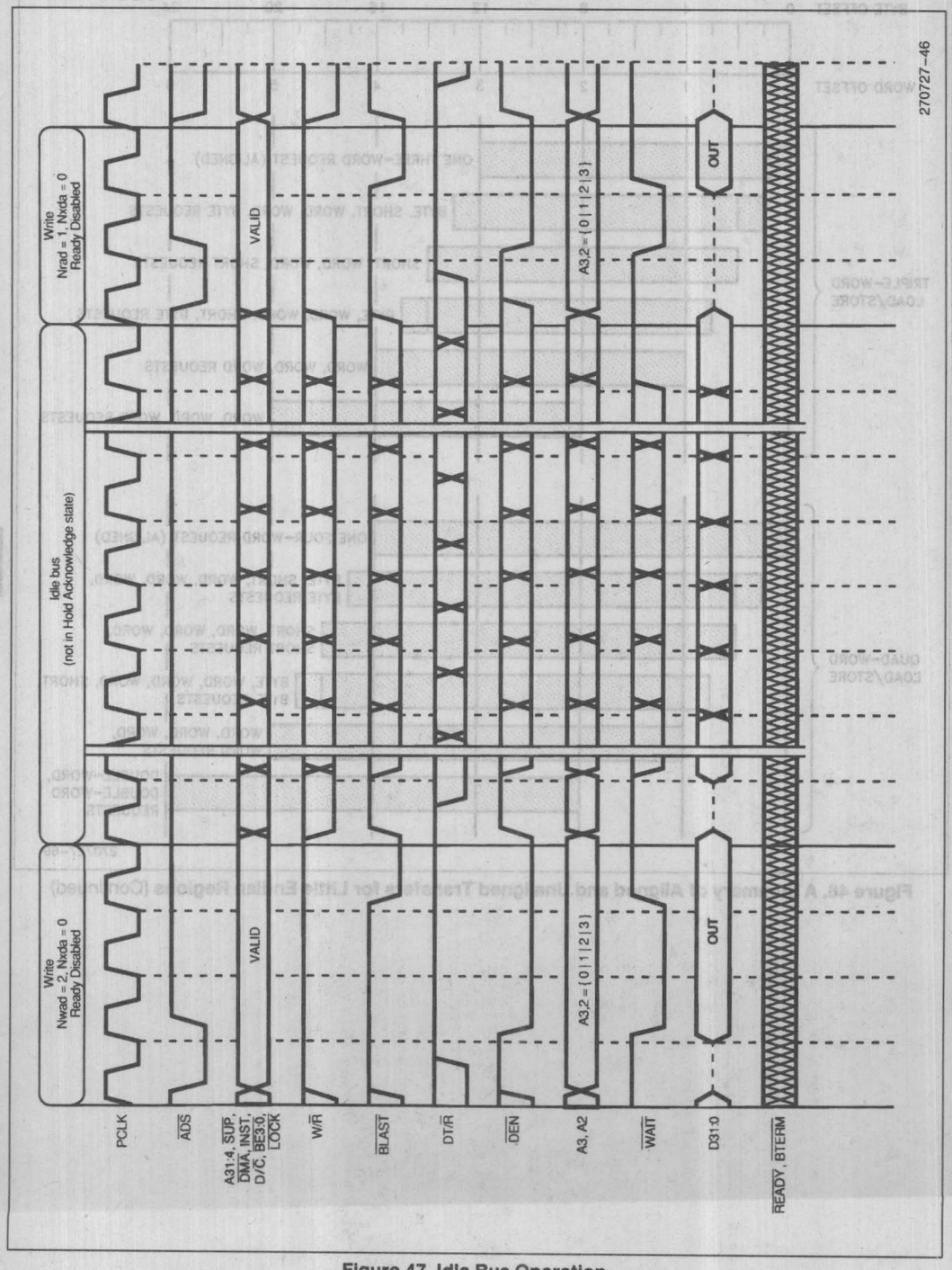


Figure 47. Idle Bus Operation

7.0 On-Circuit Emulation™ ($\overline{\text{ONCE}}$)

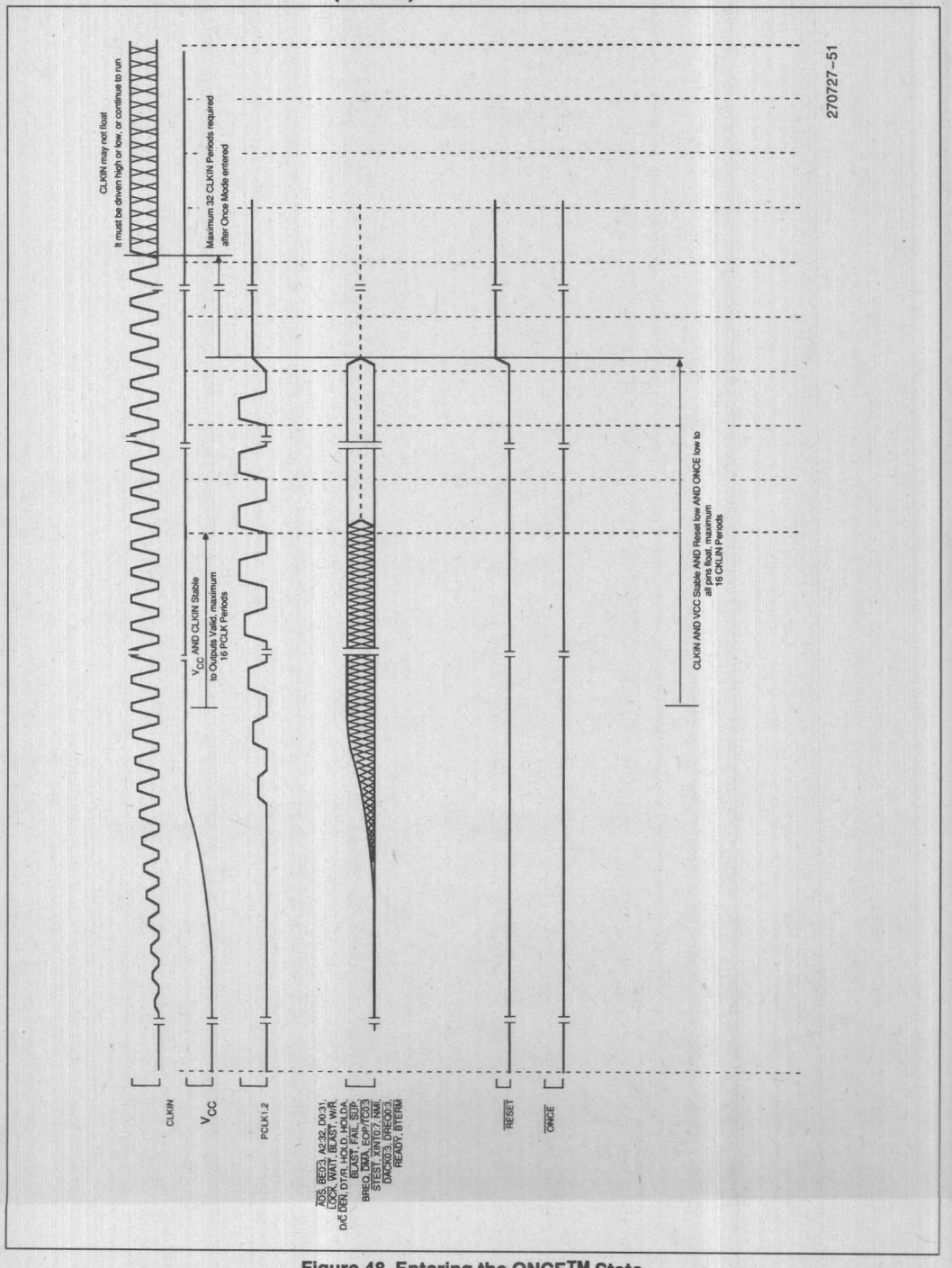


Figure 48. Entering the ONCE™ State

7.0 On-Circuit Emulation™ (ONCE)

Figure 48. Entering the ONCE™ State

80960MC Product Overview and Data Sheets

5

5 80960MC Product Overview and Data Sheets

80960MC PRODUCT OVERVIEW

This chapter provides an overview of the architecture of the 80960MC processor.

The 80960MC processor is the military-grade member of a new family of processors from Intel. This processor family is based on a new 32-bit architecture called the 80960 architecture. The 80960 architecture has been designed specifically to meet the needs of embedded applications such as avionics, aerospace, weapons systems, robotics, and instrumentation, where high reliability is critical. It represents a renewed commitment from Intel to provide reliable. high-performance processors and controllers for the embedded processor marketplace.

The 80960 architecture can best be characterized as a high-performance computing engine. It features high-speed instruction execution and ease of programming. It is also easily extensible, allowing processors and controllers based on this architecture to be conveniently customized to meet the needs of specific processing and control applications.

Some of the important attributes of the 80960 architecture include:

- full 32-bit registers
- high-speed, pipelined instruction execution
- a convenient program execution environment with 32 general-purpose registers and a versatile set of special-function registers
- a highly optimized procedure call mechanism that features on-chip caching of local variables and parameters
- extensive facilities for handling interrupts and faults
- extensive tracing facilities to support efficient program debugging and monitoring
- register scoreboarding and write buffering to permit efficient operation with lower performance memory subsystems

The 80960MC processor implements the 80960 architecture, plus it offers several extensions to the architecture. Some of these extensions, such as on-chip support for floating-point arithmetic, virtual memory management, and multitasking, are designed to enhance overall system performance. Several other extensions are designed to enhance system reliability and robustness. These extensions include facilities for hardware enforced protection of software modules and for creating fault tolerant systems through the use of redundant processors.

The following sections describe those features of the 80960 architecture that are provided to streamline code execution and simplify programming. The extensions to this architecture provided in the 80960MC processor are described at the end of the chapter.

HIGH PERFORMANCE PROGRAM EXECUTION

Much of the design of the 80960 architecture has been aimed at maximizing the processor's computational and data processing speed through increased parallelism. The following paragraphs describe several of the mechanisms and techniques used to accomplish this goal, including:

- an efficient load and store memory-access model
- caching of code and procedural data
- overlapped execution of instructions
- many one or two clock-cycle instructions

Load and Store Model

One of the more important features of the 80960 architecture is that most of its operations are performed on operands in registers, rather than in memory. For example, all the arithmetic, logical, comparison, branching, and bit operations are performed with registers and literals.

This feature provides two benefits. First, it increases program execution speed by minimizing the number of memory accesses required to execute a program. Second. it reduces memory latency encountered when using slower, lower-cost memory parts.

To support this concept, the architecture provides a generous supply of general-purpose registers. For each procedure, 32 registers are available (28 of which are available for general use). These registers are divided into two types: global and local. Both these types of registers can be used for general storage of operands. The only difference is that global registers retain their contents across procedure boundaries, whereas the processor allocates a new set of local registers each time a new procedure is called.

The architecture also provides a set of fast, versatile load and store instructions. These instructions allow burst transfers of 1, 2, 4, 8, 12, or 16 bytes of information between memory and the registers.

On-Chip Caching of Code and Data

To further reduce memory accesses, the architecture offers two mechanisms for caching code and data on chip: an instruction cache and multiple sets of local registers. The instruction cache allows prefetching of blocks of instruction from memory, which helps insure that the instruction execution pipeline is supplied with a steady stream of instructions. It also reduces the number of memory accesses required when performing iterative operations such as loops. (The size of the instruction cache can vary. With the 80960MC processor, it is 512 bytes.)

To optimize the architecture's procedure call mechanism, the processor provides multiple sets of local registers. This allows the processor to perform most procedure calls without having to write the local registers out to the stack in memory.

(The number of local-register sets provided depends on the processor implementation. The 80960MC processor provides four sets of local registers.)

Overlapped Instruction Execution

Another technique that the 80960 architecture employs to enhance program execution speed is overlapping the execution of some instructions. This is accomplished through two mechanisms: register scoreboarding and branch prediction.

Register scoreboarding permits instruction execution to continue while data is being fetched from memory. When a load instruction is executed, the processor sets one or more scoreboard bits to indicate the target registers to be loaded. After the target registers are loaded, the scoreboard bits are cleared. While the target registers are being loaded, the processor is allowed to execute other instructions that do not use these registers. The processor uses the scoreboard bits to insure that target registers are not used until the loads are complete. (The checking of scoreboard bits is transparent to software.) The net result of using this technique is that code can often be optimized in such a way as to allow some instructions to be executed parallel.

Single-Clock Instructions

It is the intent of the 80960 architecture that a processor be able to execute commonly used instructions such as move, add, subtract, logical operations, compare and branch in a minimum number of clock cycles (preferably one clock cycle). The architecture supports this concept in several ways. For example, the load and store model described earlier in this chapter (with its concentration on register-to-register operations) allows simple operations to be performed without the overhead of memory-to-memory operations.

Also, all the instructions in the 80960 architecture are 32 bits or 64 bits long and aligned on 32-bit boundaries. This feature allows instructions to be decoded in one clock cycle. It also eliminates the need for an instruction-alignment stage in the pipeline.

The design of the 80960MC processor takes full advantage of these features of the architecture, resulting in more than 50 instructions that can be executed in a single clock-cycle.

Efficient Interrupt Model

The 80960 architecture provides an efficient mechanism for servicing interrupts from external sources. To handle interrupts, the processor maintains an interrupt table of 248 interrupt vectors (240 of which are available for general use). When an interrupt is signaled, the processor uses a pointer from the interrupt table to perform an implicit call to an interrupt handler procedure. In performing this call, the processor automatically saves the state of the processor prior to receiving the interrupt; performs the interrupt routine; and then restores the state of the processor. A separate interrupt stack is also provided to segregate interrupt handling from application programs.

The interrupt handling facilities also feature a method of prioritizing interrupts. Using this technique, the processor is able to store interrupts that are lower in priority than the task the processor is currently working on in a pending interrupt section of the interrupt table. At certain defined times, the processor checks the pending interrupts and services them.

SIMPLIFIED PROGRAMMING ENVIRONMENT

Partly as a side benefit of its streamlined execution environment and partly by design, processors based on the 80960 architecture are particularly easy to program. For example, the large number of general-purpose registers allows relatively complex algorithms to be executed with a minimum number of memory accesses. The following paragraphs describe some of the other features that simplify programming.

Highly Efficient Procedure Call Mechanism

The procedure call mechanism makes procedure calls and parameter passing between procedures simple and compact. Each time a call instruction is issued, the processor automatically saves the current set of local registers and allocates a new set of local registers for the called procedure. Likewise, on a return from a procedure, the current set of local registers is deallocated and the local registers for the procedure being returned to are restored. On a procedure call, the program thus never has to explicitly save and restore those local variables and parameters that are stored in local registers.

Versatile Instruction Set and Addressing

The selection of instructions and addressing modes also simplifies programming. The architecture offers a full set of load, store, move, arithmetic, comparison, and branch instructions, with operations on both integer and ordinal data types. It also provides a complete set of Boolean and bit-field instructions, to simplify operations on bits and bit strings.

The addressing modes are efficient and straightforward, while at the same time providing the necessary indexing and scaling modes required to address complex arrays and record structures.

The large 4-gigabyte address space provides ample room to store programs and data. The availability of 32 addressing lines allows some address lines to be memory-mapped to control hardware functions.

Extensive Fault Handling Capability

To aid in program development, the 80960 architecture defines a wide selection of faults that the processor detects, including arithmetic faults, invalid operands, invalid operations, and machine faults. When a fault is detected, the processor makes an implicit call to a fault handler routine, using a mechanism similar to that described above for interrupts. The information collected for each fault allows program developers to quickly correct faulting code. It also allows automatic recovery from some faults.

Debugging and Monitoring

To support debugging systems, the 80960 architecture provides a mechanism for monitoring processor activity by means of trace events. The processor can be configured to detect as many as seven different trace events, including branches, calls, supervisor calls, returns, prereturns, breakpoints, and the execution of any instruction. When the processor detects a trace event, it signals a trace fault and calls a fault handler. Intel provides several tools that use this feature, including an in-circuit emulator (ICE) device.

SUPPORT FOR ARCHITECTURAL EXTENSIONS

The 80960 architecture described earlier in this chapter provides a high-performance computing engine for use as the computational and data-processing core of embedded processors or controllers. The architecture also provides several features that enable processors based on this architecture to be easily customized to meet the needs of specific embedded applications, such as signal processing, array processing, or graphics processing.

The most important of these features is a set of 32 special-function registers. These registers provide a convenient interface to circuitry in the processor or to pins that can be connected to external hardware. They can be used to control timers, to perform operations on special data types, or to perform I/O functions.

The special-function registers are similar to the global registers. They can be addressed by all the register-access instructions.

EXTENSIONS INCLUDED IN THE 80960MC PROCESSOR

The extensions to the 80960 architecture included in the 80960MC processor are built on top of the processor's core computing engine. These extensions are aimed at improving the efficiency and reliability of embedded systems.

On-Chip Floating Point

The 80960MC processor provides a complete implementation of the IEEE standard for binary floating-point arithmetic (IEEE 754-185). This implementation includes a full set of floating-point operations, including add, subtract, multiply, divide, trigonometric functions, and logarithmic functions. These operations are performed on single precision (32-bit), double precision (64-bit), and extended precision (80-bit) real numbers.

One of the benefits of this implementation is that the floating-point handling facilities are completely integrated into the normal instruction execution environment. Single- and double-precision floating-point values are stored in the same registers as non-floating point values. Also, four 80-bit floating-point registers are provided to hold extended-precision values.

String and Decimal Operations

The 80960MC processor provides several instructions for moving, filling, and comparing byte strings in memory. These instructions speed up string operations and reduce the amount of code required to handle strings.

The decimal instructions perform move, add with carry, and subtract with carry operations on binary-coded decimal (BCD) strings.

Virtual-Memory Support

Another of the 80960MC processor's important features is support for virtual-memory management. When using the processor in virtual-memory mode, the processor provides each process (or task) with an address space of up to 2^{32} bytes. This address space is paged into physical memory in 4K-byte pages. On-chip memory-management facilities handle virtual-to-physical address translation. A translation look-aside buffer (TLB) speeds address translation by storing virtual-to-physical address translations for frequently accessed parts of memory, such as the location of the page tables and the location of often used system data structures.

Protection

The 80960MC processor offers two mechanisms for protecting critical data structures or software modules. The first is the ability to use page rights bits to restrict access to individual pages. Page rights allow various levels of access to be assigned to a page, ranging from no access to read only to read-write.

The second protection mechanism is a user/supervisor protection model. This two-level protection model provides hardware enforced protection of kernel procedures and data structures. When using this protection mechanism, privileged procedures and data are placed in protected pages of memory. These pages can then be accessed only through a procedure table, which provides a tightly controlled interface to kernel functions.

Multitasking

The 80960MC processor offers a variety of process management facilities to support concurrent execution of multiple tasks. These facilities can be divided into two groups: process scheduling and interprocess communications.

The process scheduling facilities consist of a set of general-purpose data structures and instructions, which are designed to support several different multitasking schemes. For example, the processor provides a set of instructions that allow the kernel to explicitly dispatch a task (bind it to the processor) and to suspend a task (save the current state of a task so that another task can be bound to the processor). These instructions can be used within kernel procedures to schedule, dispatch, and preempt multiple tasks.

The processor also provides a unique feature called *self dispatching*. Here, the kernel schedules tasks by queuing them to a dispatch port. Thereafter, the processor handles the dispatching,

preempting, and rescheduling of the tasks automatically, independent of the kernel. When using this mechanism, tasks can be scheduled by priority, with up to 32 priority levels to choose from.

The processor's interprocess communication facilities include support for semaphores and communication ports. These facilities allow synchronization of interdependent tasks and asynchronous communication between tasks.

Multiprocessing

The 80960MC processor provides several mechanisms designed to simplify the design of multiple-processor systems, allowing several processors to run in parallel, using shared memory resources. One of these mechanisms is the self-dispatching capability described above. Here, two or more processors can schedule and dispatch processes from a single dispatch port, with each processor equally sharing the processing load.

The processor also provides an inter-agent communication (IAC) mechanism that allows processors to exchange messages among themselves on the bus. This mechanism operates similarly to the interrupt mechanism, except that IAC messages are passed through dedicated sections of memory. The IAC mechanism can be used to preempt processes running on another processor, to manage interrupt handling, or to initialize and synchronize several processors .

A set of atomic instructions are also provided to synchronize memory accesses. Multiple processors can then access shared memory without inserting inaccuracies and ambiguities into shared data structures.

Fault Tolerance

The 80960 family of components supports fault-tolerant system design through the use of the M82965 Bus Extension Unit component. The M82965 allows two processors to be operated in tandem to form a self-checking module. The two M82965s check the outputs of two processors (a master and a checker) cycle-by-cycle. If the checking M82965 detects a difference between outputs, it signals an error. A software recovery procedure can then be initiated.

This fault detection mechanism supports several fault detection and recovery techniques, including self healing, and continuous-operation (non-stop) systems.

LOOK FOR MORE IN THE FUTURE

The 80960 architecture offers exceptional performance, plus a wealth of useful features to help in the design of efficient and reliable embedded systems. But equally important, it offers lots of room to grow. The 80960MC processor provides average instruction processing rates of 7.5 million instructions per second (7.5 MIPS) at 20 MHz clock rate and 10 MIPS at a 25 MHz clock rate[1].

[1] 1 MIP is equivalent to the performance of a Digital Equipment Corp. VAX 11/780.

However, the 80960MC is only the beginning. With improvements in VLSI technology, future implementations of the 80960 architecture will offer even greater performance. They will also offer a variety of useful extensions to solve specific control and monitoring needs in the field of embedded applications.

80960MC
EMBEDDED 32-BIT MICROPROCESSOR WITH INTEGRATED FLOATING-POINT UNIT AND MEMORY MANAGEMENT UNIT

Military

- **High-Performance Embedded Architecture**
  - **25 MIPS Burst Execution at 20 MHz**
  - **9.4 MIPS* Sustained Execution at 25 MHz**
- **On-Chip Floating-Point Unit**
  - **Supports IEEE 754 Floating-Point Standard**
  - **Full Transcendental Support**
  - **Four 80-Bit Registers**
  - **5.2 Million Whetstones/Second at 25 MHz**
- **512-Byte On-Chip Instruction Cache**
  - **Direct Mapped**
  - **Parallel Load/Decode for Uncached Instructions**
- **Multiple Register Sets**
  - **Sixteen Global 32-Bit Registers**
  - **Sixteen Local 32-Bit Registers**
  - **Four Local Register Sets Stored On-Chip (Sixteen 32-Bit Registers per Set)**
  - **Register Scoreboarding**
- **On-Chip Memory Management Unit**
  - **4 Gigabyte Virtual Address Space per Task**
  - **4 Kbyte Pages with Supervisor/User Protection**
- **Built-In Interrupt Controller**
  - **32 Priority Levels**
  - **248 Vectors**
  - **Supports M8259A**
  - **3.4 μs Latency**
- **Easy to Use, High Bandwidth 32-Bit Bus**
  - **66.7 MBytes/s Burst**
  - **Up to 16-Bytes Transferred per Burst**
- **Multitasking and Multiprocessor Support**
  - **Automatic Task Dispatching**
  - **Prioritized Task Queues**
- **Advanced Package Technology**
  - **132 Lead Ceramic Pin Grid Array**
  - **164 Lead Ceramic Quad Flatpack**
- **Military Temperature Range**
  - **−55°C to +125°C (T_C)**

5

The 80960MC is the enhanced military member of Intel's new 32-bit microprocessor family, the 960 series, which is designed especially for embedded applications. It is based on the family's high performance, common core architecture, and includes a 512-byte instruction cache, a built-in interrupt controller, an integrated floating-point unit and a memory management unit. The 80960MC has a large register set, multiple parallel execution units, and a high-bandwidth, burst bus. Using advanced RISC technology, this high performance processor can respond to interrupts in under 3.4 μs and is capable of execution rates in excess of 9.4 million instructions per second.* The 80960MC is well-suited for a wide range of military and other high reliability applications, including avionics, airborne radar, navigation, and instrumentation.

*Relative to Digital Equipment Corporation's VAX-11/780** at 1 MIPS

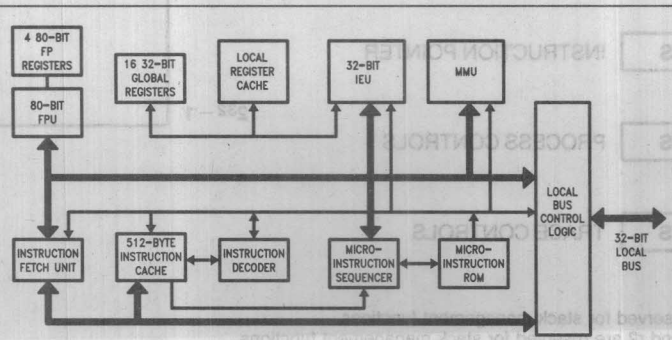


Figure 1. The 80960MC's Highly Parallel Microarchitecture

**VAX-11™ is a trademark of Digital Equipment Corporation.

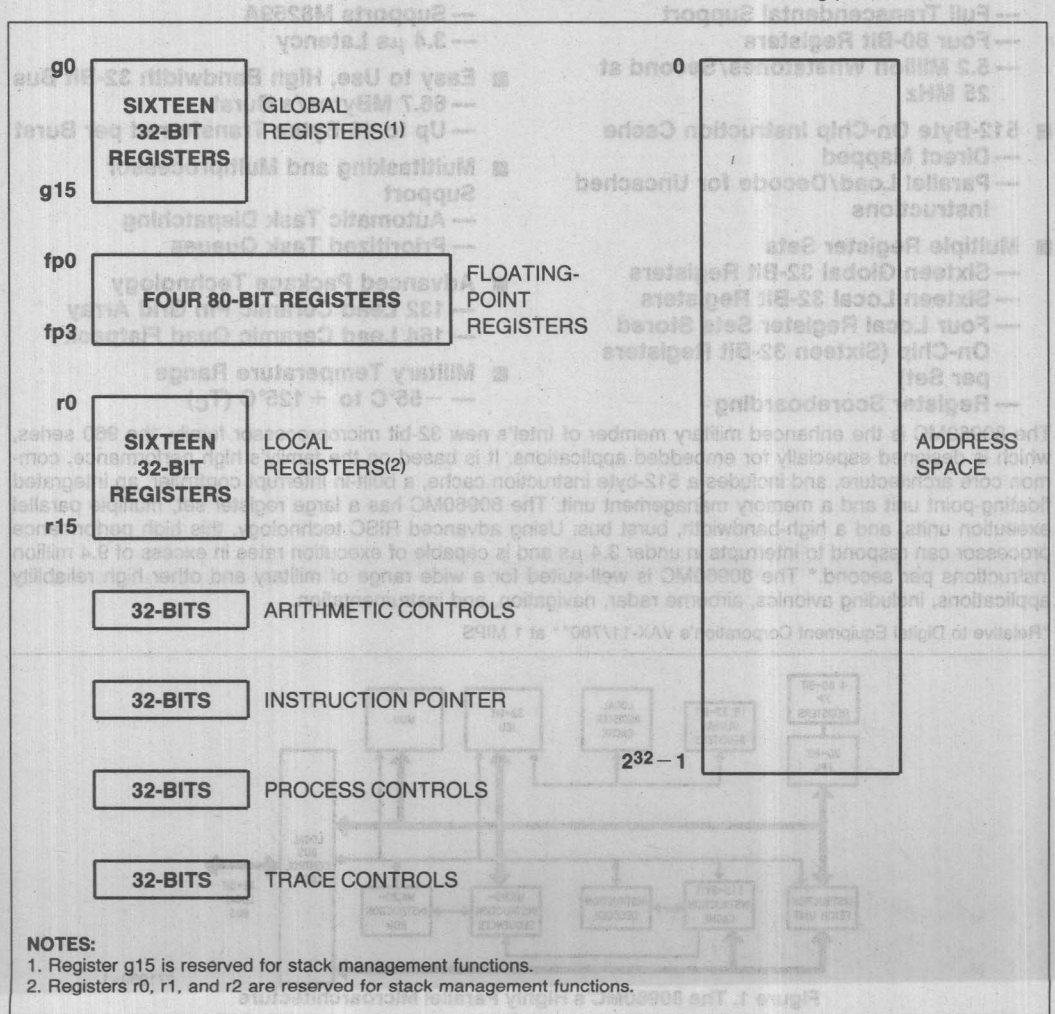
August 1990
Order Number: 271080-005

THE 960 SERIES

The 80960MC is the enhanced military member of a new family of 32-bit microprocessors from Intel known as the 960 Series. This series was especially designed to serve the needs of embedded applications. The embedded market includes applications as diverse as industrial automation, avionics, image processing, graphics, robotics, telecommunications, and automobiles. These types of applications require high integration, low power consumption, quick interrupt response times, and high performance. Since time to market is critical, embedded microprocessors need to be easy to use in both hardware and software designs.

All members of the 80960 series share a common core architecture which utilizes RISC technology so that, except for special functions, the family members are object code compatible. Each new processor in the series will add its own special set of functions to the core to satisfy the needs of a specific application or range of applications in the embedded market. For example, future processors may include a DMA controller, a timer, or an A/D converter.

The 80960MC includes an integrated Floating Point Unit (FPU), a Memory Management Unit (MMU), multitasking support, and multiprocessor support. There are also two commercial members of the family: the 80960KB processor with integrated FPU and the 80960KA without floating-point.



NOTES:
1. Register g15 is reserved for stack management functions.
2. Registers r0, r1, and r2 are reserved for stack management functions.

Figure 2. Register Set

KEY PERFORMANCE FEATURES

The 80960MC's architecture is based on the most recent advances in RISC technology and is grounded in Intel's long experience in designing embedded controllers. Many features contribute to the 80960MC's exceptional performance:

1. Large Register Set. Having a large number of registers reduces the number of times that a processor needs to access memory. Modern compilers can take advantage of this feature to optimize execution speed. For maximum flexibility, the 80960MC provides thirty-two 32-bit registers (sixteen local and sixteen global) and four 80-bit floating-point global registers. (See Figure 2.)

2. Fast Instruction Execution. Simple functions make up the bulk of instructions in most programs, so that execution speed can be greatly improved by ensuring that these core instructions execute in as short a time as possible. The most-frequently executed instructions such as register-register moves, add/subtract, logical operations, and shifts execute in one to two cycles (Table 1 contains a list of instructions.)

3. Load/Store Architecture. Like other processors based on RISC technology, the 80960MC has a Load/Store architecture, only the LOAD and STORE instructions reference memory; all other instructions operate on registers. This type of architecture simplifies instruction decoding and is used in combination with other techniques to increase parallelism.

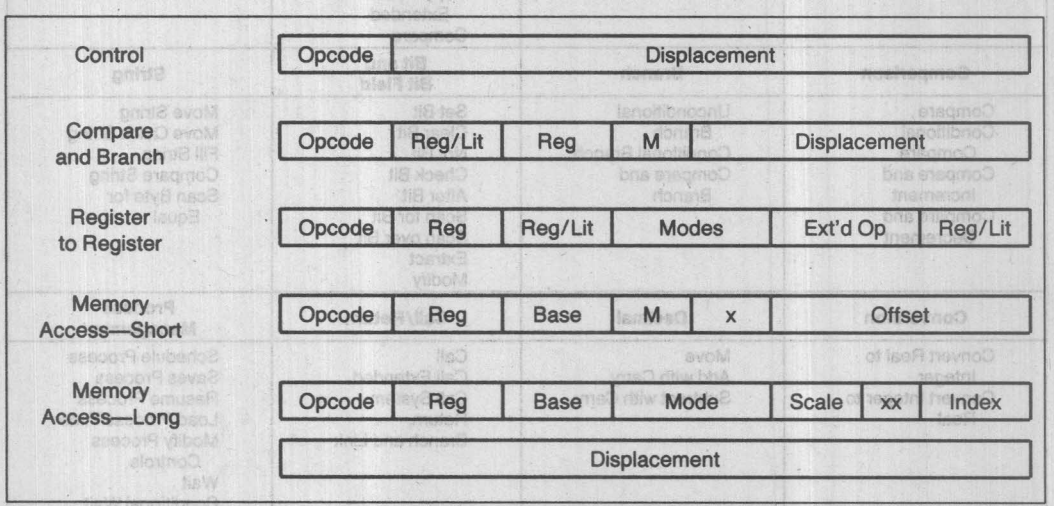


Figure 3. Instruction Formats

5

Table 1. 80960MC Instruction Set

Data Movement	Arithmetic	Floating Point	Logical
Load Store Move Load Address Load Physical Address	Add Subtract Multiply Divide Remainder Modulo Shift	Add Subtract Multiply Divide Remainder Scale Round Square Root Sine Cosine Tangent Arctangent Log Log Binary Log Natural Exponent Classify Copy Real Extended Compare	And Not And And Not Or Exclusive Or Not Or Or Not Nor Exclusive Nor Not Nand Rotate
Comparison	**Branch**	**Bit and Bit Field**	**String**
Compare Conditional Compare Compare and Increment Compare and Decrement	Unconditional Branch Conditional Branch Compare and Branch	Set Bit Clear Bit Not Bit Check Bit Alter Bit Scan for Bit Scan over Bit Extract Modify	Move String Move Quick String Fill String Compare String Scan Byte for Equal
Conversion	**Decimal**	**Call/Return**	**Process Management**
Convert Real to Integer Convert Integer to Real	Move Add with Carry Subtract with Carry	Call Call Extended Call System Return Branch and Link	Schedule Process Saves Process Resume Process Load Process Time Modify Process Controls Wait Conditional Wait Signal Receive Conditional Receive Send Send Service Atomic Add Atomic Modify
Fault	**Debug**	**Miscellaneous**	
Conditional Fault Synchronize Faults	Modify Trace Controls Mark Force Mark	Flush Local Registers Inspect Access Modify Arithmetic Controls Test Condition Code	

4. Simple Instruction Formats. All instructions in the 80960MC are 32-bits long and must be aligned on word boundaries. This alignment makes it possible to eliminate the instruction-alignment stage in the pipeline. To simplify the instruction decoder further, there are only five instruction formats and each instruction uses only one format. (See Figure 3.)

5. Overlapped Instruction Execution. A load operation allows execution of subsequent instructions to continue before the data has been returned from memory, so that these instructions can overlap the load. The 80960MC manages this process transparently to software through the use of a register scoreboard. Conditional instructions also make use of a scoreboard so that subsequent unrelated instructions can be executed while the conditional instruction is pending.

6. Integer Execution Optimization. When the result of an operation is used as an operand in a subsequent calculation, the value is sent immediately to its destination register. Yet at the same time, the value is put back on a bypass path to the ALU, thereby saving the time that otherwise would be required to retrieve the value for the next operation.

7. Bandwidth Optimizations. The 80960MC gets optimal use of its memory bus bandwidth because the bus is tuned for use with the cache: the line size of the instruction cache matches the maximum burst size for instruction fetches. The 80960MC automatically fetches four words in a burst and stores them directly in the cache. Due to the size of the cache and the fact that it is continually filled in anticipation of needed instructions in the program flow, the 80960MC is exceptionally insensitive to memory wait states. In fact, each wait state causes only a 7% degradation in system perfomance. The benefit is that the 80960MC will deliver outstanding performance even with a low cost memory system.

8. Cache Bypass. If there is a cache miss, the processor fetches the needed instruction, then sends it on to the instruction decoder at the same time it updates the cache. Thus, no extra time is taken to load and read the cache.

Memory Space and Addressing Modes

The 80960MC allows each task (process) to address a logical memory space of up to 4 Gbytes. In turn, each task's address space is divided into four 1-Gbyte regions and each region can be mapped to physical addresses by zero, one, or two levels of page tables. The region with the highest addresses (Region 3) is common to all tasks.

In keeping with RISC design principles, the number of addressing modes has been kept to a minimum but includes all those necessary to ensure efficient execution of high-level languages such as Ada, C, and Fortran. Table 2 lists the memory addressing modes.

Data Types

The 80960MC recognizes the following data types:

Numeric:
- 8-, 16-, 32- and 64-bit ordinals
- 8-, 16, 32- and 64-bit integers
- 32-, 64- and 80-bit real numbers

Non-Numeric:
- Bit
- Bit Field
- Triple-Word (96 bits)
- Quad-Word (128 bits)

Large Register Set

The programming environment of the 80960MC includes a large number of registers. In fact, 36 registers are available at any time. The availability of this many registers greatly reduces the number of memory accesses required to execute most programs, which leads to greater instruction processing speed.

There are two types of general-purpose registers: local and global. The 20 global registers consist of sixteen 32-bit registers (G0 through G15) and four 80-bit registers (FP0 through FP3). These registers perform the same function as the general-purpose registers provided in other popular microprocessors. The term global refers to the fact that these registers retain their contents across procedure calls.

The local registers, on the other hand, are procedure specific. For each procedure call, the 80960MC allocates 16 local registers (R0 through R15). Each local register is 32 bits wide. Any register can also be used for floating-point operations; the 80-bit floating-point registers are provided for extended precision.

Multiple Register Sets

To further increase the efficiency of the register set, multiple sets of local registers are stored on-chip. This cache holds up to four local register frames, which means that up to three procedure calls can be made without having to access the procedure stack resident in memory.

Table 2. Memory Addressing Modes

- 12-Bit Offset
- 32-Bit Offset
- Register-Indirect
- Register + 12-Bit Offset
- Register + 32-Bit Offset
- Register + (Index-Register × Scale-Factor)
- Register × Scale Factor + 32-Bit Displacement
- Register + (Index-Register × Scale-Factor) + 32-Bit Displacement

Scale-Factor is 1, 2, 4, 8 or 16

Although programs may have procedure calls nested many calls deep, a program typically oscillates back and forth between only two or three levels. As a result, with four stack frames in the cache, the probability of there being a free frame on the cache when a call is made is very high. In fact, runs of representative C-language programs show that 80% of the calls are handled without needing to access memory.

If there are four or more active procedures and a new procedure is called, the processor moves the oldest set of local registers in the register cache to a procedure stack in memory to make room for a new set of registers. Global register G15 is used by the processor as the frame pointer (FP) for the procedure stack.

Note that the global and floating-point registers are not exchanged on a procedure call, but retain their contents, making them available to all procedures for fast parameter passing. An illustration of the register cache is shown in Figure 4.

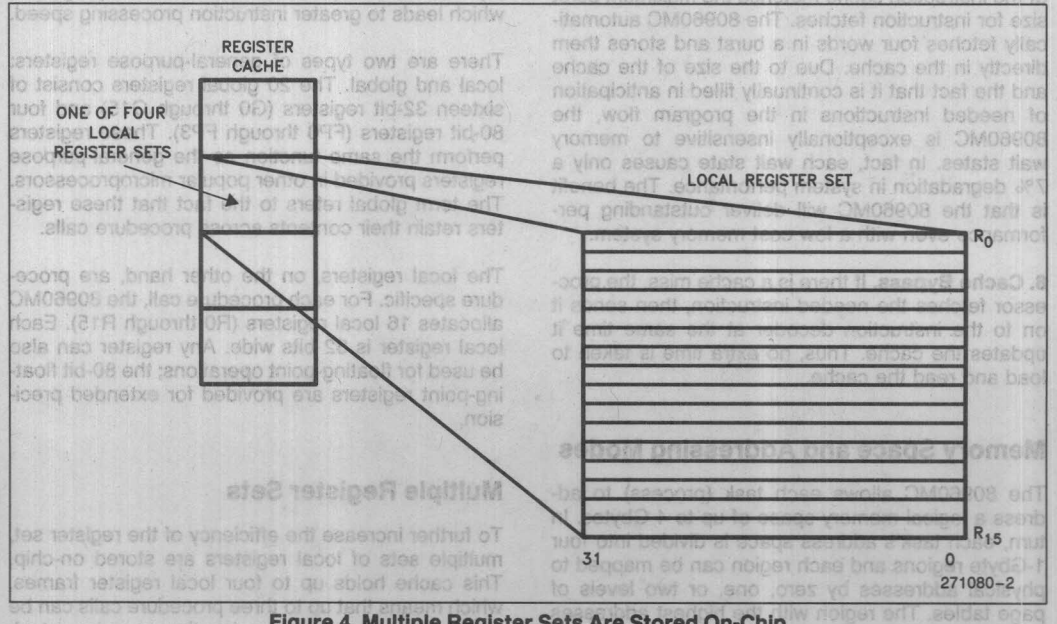


Figure 4. Multiple Register Sets Are Stored On-Chip

Instruction Cache

To further reduce memory accesses, the 80960MC includes a 512-byte on-chip instruction cache. The instruction cache is based on the concept of locality of reference; that is, most programs are not usually executed in a steady stream but consist of many branches and loops that lead to jumping back and forth within the same small section of code. Thus, by maintaining a block of instructions in a cache, the number of memory references required to read instructions into the processor can be greatly reduced.

To load the instruction cache, instructions are fetched in 16-byte blocks, so that up to four instructions can be fetched at one time. An efficient prefetch algorithm increases the probability that an instruction will already be in the cache when it is needed.

Code for small loops will often fit entirely within the cache, leading to a great increase in processing speed since further memory references might not be necessary until the program exits the loop. Similarly, when calling short procedures, the code for the calling procedure is likely to remain in the cache, so it will be there on the procedure's return.

Register Scoreboarding

The instruction decoder has been optimized in several ways. One of these optimizations is the ability to do instruction overlapping by means of register scoreboarding.

Register scoreboarding occurs when a LOAD instruction is executed to move a variable from memory into a register. When the instruction is initiated, a scoreboard bit on the target register is set. When the register is actually loaded, the bit is reset. In between, any reference to the register contents is accompanied by a test of the scoreboard bit to insure that the load has completed before processing continues. Since the processor does not have to wait for the LOAD to be completed, it can go on to execute additional instructions placed in between the LOAD instruction and the instruction that uses the register contents, as shown in the following example:

```
LOAD R4, address 1
LOAD R5, address 2
Unrelated instruction
Unrelated instruction
ADD R4, R5, R6
```

In essence, the two unrelated instructions between the LOAD and ADD instructions are executed for free (i.e., take no apparent time to execute) because they are executed while the register is being loaded. Up to three LOAD instructions can be pending at one time with three corresponding scoreboard bits set. By exploiting this feature, system programmers and compilers have a useful tool for optimizing execution speed.

Memory Management and Protection

The 80960MC will be especially useful for multitasking applications that require software protection and a very large address space. To ensure the highest level of performance possible, the memory management unit and translation look-aside buffer (TLB) are contained on-chip.

The 80960MC supports a conventional form of demand-paged virtual memory in which the address space is divided into 4 Kbyte pages. Studies have shown that a 4 Kbyte page is the optimum size for a broad range of applications.

Each page table entry includes a 2-bit page rights field that specifies whether the page is a no-access, read-only, or read-write page. This field is interpreted differently depending on whether the current task (process) is executing in user or supervisor mode, as shown below:

Rights	User	Supervisor
00	No Access	Read-Only
01	No Access	Read-Write
10	Read-Only	Read-Write
11	Read-Write	Read-Write

Floating-Point Arithmetic

In the 80960MC, floating-point arithmetic has been made an integral part of the architecture. Having the floating-point unit integrated on-chip provides two advantages. First, it improves the performance of the chip for floating-point applications, since no additional bus overhead is associated with floating-point calculations, thereby leaving more time for other bus operations such as I/O. Second, the cost of using floating-point operations is reduced because a separate coprocessor chip is not required.

The 80960MC floating-point (real number) data types include single-precision (32-bit), double-precision (64-bit), and extended precision (80-bit) floating-point numbers. Any register may be used to execute floating-point operations.

The processor provides hardware support for both mandatory and recommended portions of IEEE Standard 754 for floating-point arithmetic, including all arithmetic, exponential, logarithmic, and other transcendental functions. Table 3 shows execution times for some representative instructions.

Table 3. Sample Floating-Point Execution Times (μs) at 25 MHz

	32-Bit	64-Bit
Add	0.4	0.5
Subtract	0.4	0.5
Multiply	0.7	1.3
Divide	1.3	2.9
Square Root	3.7	3.9
Arctangent	10.1	13.1
Exponent	11.3	12.5
Sine	15.2	16.6
Cosine	15.2	16.6

Multitasking Support

Multitasking programs commonly involve the monitoring and control of an external operation, such as the activities of a process controller or the movements of a machine tool. These programs generally consist of a number of processes that run independently of one another, but share a common database or pass data among themselves.

The 80960MC offers several hardware functions designed to support multitasking systems. One unique feature, called self-dispatching, allows a processor to switch itself automatically among scheduled tasks. When self-dispatching is used, all the operating system is required to do is place the task in the scheduling queue.

When the processor becomes available, it dispatches the task from the beginning of the queue and then executes it until it becomes blocked, interrupted, or until its time-slice expires. It then returns the task to the end of the queue (i.e., automatically reschedules it) and dispatches the next ready task.

During these operations, no communication between the processor and the operating system is necessary until the running task is complete or an interrupt is issued.

Synchronization and Communication

The 80960MC also offers instructions to set up and test semaphores to ensure that concurrent tasks remain synchronized and no data inconsistency results. Special data structures, known as communication ports, provide the means for exchanging parameters and data structures. Transmission of information by means of communication ports is asynchronous and automatically buffered by the processor.

Communication between tasks by means of ports can be carried out independently of the operating system. Once the ports have been set up by the programmer, the processor handles the message passing automatically.

High Bandwidth Local Bus

An 80960MC CPU resides on a high-bandwidth address/data bus known as the local bus (L-Bus). The L-Bus provides a direct communication path between the processor and the memory and I/O subsystem interfaces. The processor uses the local bus to fetch instructions, manipulate memory, and respond to interrupts. Its features include:

- 32-bit multiplexed address/data path
- Four-word burst capability, which allows transfers from 1 to 16 bytes at a time
- High bandwidth reads and writes at 66.7 MBytes per second
- Special signal to indicate whether a memory transaction can be cached

Figure 5 identifies the groups of signals which constitute the L-Bus. Table 4 lists the function of the L-Bus and other processor-support signals, such as the interrupt lines.

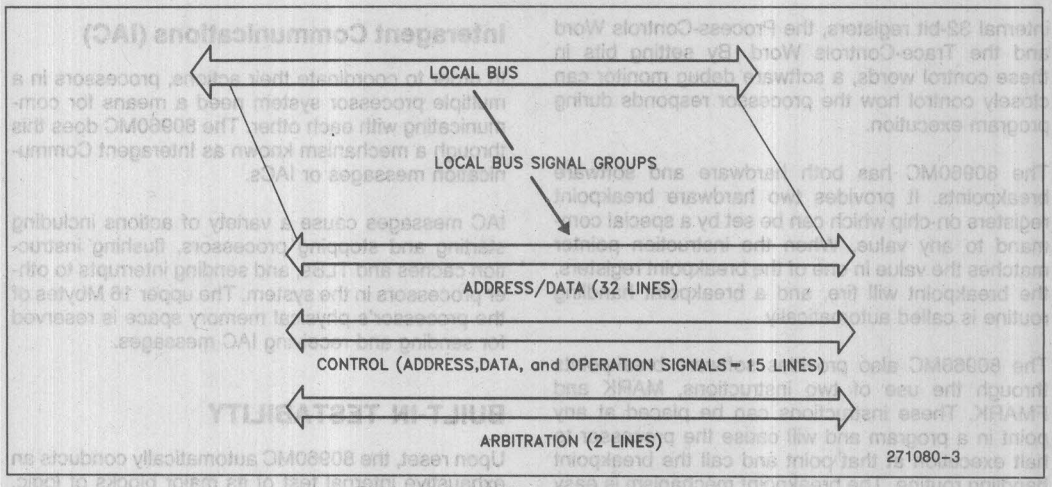


Figure 5. Local Bus Signal Groups

Multiple Processor Support

One means of increasing the processing power of a system is to run two or more processors in parallel. Since microprocessors are not generally designed to run in tandem with other processors, designing such a system is usually difficult and costly.

The 80960MC solves this problem by offering a number of functions to coordinate the actions of multiple processors. First, messages can be passed between processors to initiate actions such as flushing a cache, stopping or starting another processor, or preempting a task. The messages are passed on the bus and allow multiple processors to run together smoothly, with rare need to lock the bus or memory.

Second, a set of synchronization instructions help maintain the coherency of memory. These instructions permit several processors to modify memory at the same time without inserting inaccuracies or ambiguities into shared data structures.

The self-dispatching mechanism, in addition to being used in single-processor systems, provides the means to increase the performance of a system merely by adding processors. Each processor can either work on the same pool of tasks (sharing the same queue with other processors) or can be restricted to its own queue.

When processors perform system operations, they synchronize themselves by using atomic operations and sending special messages between each other. *And changing the number of processors in a system* never requires a software change. Software will execute correctly regardless of the number of processors in the system; systems with more processors simply execute faster.

Interrupt Handling

The 80960MC can be interrupted in one of two ways: by the activation of one of four interrupt pins or by sending a message on the processor's data bus.

The 80960MC is unusual in that it automatically handles interrupts on a priority basis and tracks pending interrupts through its on-chip interrupt controller. Two of the interrupt pins can be configured to provide M8259A handshaking for expansion beyond four interrupt lines.

An interrupt message is made up of a vector number and an interrupt priority. If the interrupt priority is greater than that of the currently running task, the processor accepts the interrupt and uses the vector as an index into the interrupt table. If the priority of the interrupt message is below that of the current task, the processor saves the information in a section of the interrupt table reserved for pending interrupts.

Debug Features

The 80960MC has built-in debug capabilities. There are two types of breakpoints and six different trace modes. The debug features are controlled by two

internal 32-bit registers, the Process-Controls Word and the Trace-Controls Word. By setting bits in these control words, a software debug monitor can closely control how the processor responds during program execution.

The 80960MC has both hardware and software breakpoints. It provides two hardware breakpoint registers on-chip which can be set by a special command to any value. When the instruction pointer matches the value in one of the breakpoint registers, the breakpoint will fire, and a breakpoint handling routine is called automatically.

The 80960MC also provides software breakpoints through the use of two instructions, MARK and FMARK. These instructions can be placed at any point in a program and will cause the processor to halt execution at that point and call the breakpoint handling routine. The breakpoint mechanism is easy to use and provides a powerful debugging tool.

Tracing is available for instructions (single-step execution), calls and returns, and branching. Each different type of trace may be enabled separately by a special debug instruction. In each case, the 80960MC executes the instruction first and then calls a trace handling routine (usually part of a software debug monitor). Further program execution is halted until the trace routine is completed. When the trace event handling routine is completed, instruction execution resumes at the next instruction. The 80960MC's tracing mechanisms, which are implemented completely in hardware, greatly simplify the task of testing and debugging software.

FAULT DETECTION

The 80960MC has an automatic mechanism to handle faults. There are ten fault types including trace, arithmetic, and floating-point faults. When the processor detects a fault, it automatically calls the appropriate fault handling routine and saves the current instruction pointer and necessary state information to make efficient recovery possible. The processor posts diagnostic information on the type of fault to a Fault Record. Like interrupt handling routines, fault handling routines are usually written to meet the needs of a specific application and are often included as part of the operating system or kernel.

For each of the ten fault types, there are numerous subtypes that provide specific information about a fault. For example, a floating-point fault may have its subtype set to an Overflow or Zero-Divide fault. The fault handler can use this specific information to respond correctly to the fault.

Interagent Communications (IAC)

In order to coordinate their actions, processors in a multiple processor system need a means for communicating with each other. The 80960MC does this through a mechanism known as Interagent Communication messages or IACs.

IAC messages cause a variety of actions including starting and stopping processors, flushing instruction caches and TLBs, and sending interrupts to other processors in the system. The upper 16 Mbytes of the processor's physical memory space is reserved for sending and receiving IAC messages.

BUILT-IN TESTABILITY

Upon reset, the 80960MC automatically conducts an exhaustive internal test of its major blocks of logic.

Then, before executing its first instruction, it does a zero check sum on the first eight words in memory to ensure that the system has been loaded correctly. If a problem is discovered at any point during the self-test, the 80960MC will assert its FAILURE pin and will not begin program execution. The self-test takes approximately 47,000 cycles to complete.

System manufacturers can use the 80960MC's self-test feature during incoming parts inspection. No special diagnostic programs need to be written, and the test is both thorough and fast. The self-test capability helps ensure that defective parts will be discovered before systems are shipped, and once in the field, the self-test makes it easier to distinguish between problems caused by processor failure and problems resulting from other causes.

COMPATIBILITY WITH 80960K-SERIES

Application programs written for the 80960K-Series microprocessors can be run on the 80960MC without modification. The 80960K-Series instruction set forms the core of the 80960MC's instructions, so binary compatibility is assured.

CHMOS

The 80960MC is fabricated using Intel's CHMOS IV (Complementary High Speed Metal Oxide Semiconductor) process. This advanced technology eliminates the frequency and reliability limitations of older CMOS processes and opens a new era in microprocessor performance. It combines the high performance capabilities of Intel's industry-leading HMOS technology with the high density and low power characteristics of CMOS. The 80960MC is available at 16, 20 and 25 MHz.

Table 4a. 80960MC Pin Description: L-Bus Signals

Symbol	Type	Name and Function
CLK2	I	**SYSTEM CLOCK** provides the fundamental timing for 80960MC systems. It is divided by two inside the 80960MC to generate the internal processor clock. CLK2 is shown in Figure 9.
LAD_{31} $-LAD_0$	I/O T.S.	**LOCAL ADDRESS/DATA BUS** carries 32-bit physical addresses and data to and from memory. During an address (T_a) cycle, bits 2–31 contain a physical word address (bits 0–1 indicate SIZE; see below). During a data (T_d) cycle, bits 0–31 contain read or write data. The LAD lines are active HIGH and float to a high impedance state when not active. **SIZE,** which is comprised of bits 0–1 of the LAD lines during a T_a cycle, specifies the size of a transfer in words for a burst transaction. $\underline{LAD}_1$ $\underline{LAD}_0$ 0 0 1 Word 0 1 2 Words 1 0 3 Words 1 1 4 Words
$\overline{ALE}$	O T.S.	**ADDRESS-LATCH ENABLE** indicates the transfer of a physical address. ALE is asserted during a T_a cycle and deasserted before the beginning of the T_d state. It is active LOW and floats to a high impedance state when the processor is idle or is at the end of any bus access.
$\overline{ADS}$	O O.D.	**ADDRESS STATUS** indicates an address state. ADS is asserted every T_a state and deasserted during the the following T_d state. For a burst transaction, $\overline{ADS}$ is asserted again every T_d state where $\overline{READY}$ was asserted in the previous cycle.
W/$\overline{R}$	O O.D.	**WRITE/READ** specifies, during a T_a cycle, whether the operation is a write or read. It is latched on-chip and remains valid during T_d and T_w states.
DT/$\overline{R}$	O O.D.	**DATA TRANSMIT/RECEIVE** indicates the direction of data transfer to and from the L-Bus. It is low during T_a, T_w and T_d cycles for a read or interrupt acknowledgement; it is high during T_a, T_w and T_d cycles for a write. DT/$\overline{R}$ never changes state when $\overline{DEN}$ is asserted (see Timing Diagrams).
$\overline{DEN}$	O O.D.	**DATA ENABLE** is asserted during T_d and T_w cycles and indicates transfer of data on the LAD bus lines.
$\overline{READY}$	I	**READY** indicates that data on LAD lines can be sampled or removed. If $\overline{READY}$ is not asserted during a T_d cycle, the T_d cycle is extended to the next cycle by inserting wait states (T_w), and $\overline{ADS}$ is not asserted in the next cycle.
$\overline{LOCK}$	I/O O.D.	**BUS LOCK** prevents other bus masters from gaining control of the L-Bus following the current cycle (if they would assert $\overline{LOCK}$ to do so). $\overline{LOCK}$ is used by the processor or any bus agent when it performs indivisible Read/Modify/Write (RMW) operations. For a read that is designated as a RMW-read, $\overline{LOCK}$ is examined. if asserted, the processor waits until it is not asserted; if not asserted, the processor asserts $\overline{LOCK}$ during the T_a cycle and leaves it asserted. A write that is designated as an RMW-write deasserts $\overline{LOCK}$ in the T_a cycle.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = three state
$T_a = T_{Address}$, $T_d = T_{Data}$, $T_W = T_{Wait}$, $T_r = T_{Recovery}$, $T_i = T_{Idle}$, $T_h = T_{Hold}$

Table 4a. 80960MC Pin Description: L-Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{BE_3}$–$\overline{BE_0}$	O O.D.	**BYTE ENABLE LINES** specify which data bytes (up to four) on the bus take part in the current bus cycle. $\overline{BE_3}$ corresponds to LAD_{31}–LAD_{24} and $\overline{BE_0}$ corresponds to LAD_7–LAD_0. The byte enables are provided in advance of data. The byte enables asserted during T_a specify the bytes of the first data word. The byte enables asserted during T_d specify the bytes of the next data word (if any), that is, the word to be transmitted following the next assertion of $\overline{READY}$. The byte enables during the T_d cycles preceding the last assertion of $\overline{READY}$ are undefined. The byte enables are latched on-chip and remain constant from one T_d cycle to the next when $\overline{READY}$ is not asserted. For reads, the byte enables specify the byte(s) that the processor will actually use. 80960MC's will assert only adjacent byte enables (e.g., asserting just $\overline{BE_0}$ and $\overline{BE_2}$ is not permitted), and are required to assert at least one byte enable. Accesses must also be naturally aligned (e.g., asserting $\overline{BE_1}$ and $\overline{BE_2}$ is not allowed even though they are adjacent). To produce address bits A_0 and A_1 externally, they can be decoded from the byte enables.
HOLD (HLDAR)	I	**HOLD** indicates a request from a secondary bus master to acquire the bus. If the processor is initialized as the primary bus master this input will be interpreted as HOLD. When the processor receives HOLD and grants another master control of the bus, it floats its three-state bus lines, asserts HOLD ACKNOWLEDGE, and enters the T_h state. When HOLD is deasserted, the processor will deassert HOLD ACKNOWLEDGE and go to either the T_i or T_a state. **HOLD ACKNOWLEDGE RECEIVED** indicates that the processor has acquired the bus. If the processor is initialized as the secondary bus master this input is interpreted as HLDAR. HOLD timing is shown in Figure 11.
HLDA (HOLDR)	O T.S.	**HOLD ACKNOWLEDGE** relinquishes control of the bus to another bus master. If the processor is initialized as the primary bus master this output will be interpreted as HLDA. When HOLD is deasserted, the processor will deassert HLDA and go to either the T_i or T_a state. **HOLD REQUEST** indicates a request to acquire the bus. If the processor is initialized as the secondary bus master this output will be interpreted as HOLDR. HOLD timing is shown in Figure 11.
CACHE	O T.S.	**CACHE** indicates if an access is cacheable during a T_a cycle. The CACHE signal floats to a high impedance state when the processor is idle.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = three state
$T_a = T_{Address}$, $T_d = T_{Data}$, $T_W = T_{Wait}$, $T_r = T_{Recovery}$, $T_i = T_{Idle}$, $T_h = T_{Hold}$

Table 4b. 80960MC Pin Description: Module Support Signals

Symbol	Type	Name and Function
$\overline{BADAC}$	I	**BAD ACCESS,** if asserted in the cycle following the one in which the last $\overline{READY}$ of a transaction is asserted, indicates that an unrecoverable error has occurred on the current bus transaction, or that a synchronous load/store instruction has not been acknowledged. **STARTUP:** During system reset, the $\overline{BADAC}$ signal is interpreted differently. If the signal is high, it indicates that this processor will perform system initialization. If it is low, another processor in the system will perform system initialization instead.
RESET	I	**RESET** clears the internal logic of the processor and causes it to re-initialize. During RESET assertion, the input pins are ignored (except for $\overline{BADAC}$ and $\overline{IAC}/\overline{INT_0}$), the tri-state output pins are placed in a high impedance state, and other output pins are placed in their non-asserted state. RESET must be asserted for at least 41 CLK2 cycles for a predictable RESET. The HIGH to LOW transition of RESET should occur after the rising edge of both CLK2 and the external bus CLK, and before the next rising edge of CLK2. RESET timing is shown in Figure 10.
$\overline{FAILURE}$	O O.D.	**INITIALIZATION FAILURE** indicates that the processor has failed to initialize correctly. After RESET is deasserted and before the first bus transaction begins, $\overline{FAILURE}$ is asserted while the processor performs a self-test. If the self-test completes successfully, then $\overline{FAILURE}$ is deasserted. Next, the processor performs a zero checksum on the first eight words of memory. If it fails, $\overline{FAILURE}$ is asserted for a second time and remains asserted; if it passes, system initialization continues and $\overline{FAILURE}$ remains deasserted.
N.C.	N/A	**NOT CONNECTED** indicates pins should not be connected. Never connect any pin marked N.C.
$\overline{IAC}$ ($\overline{INT_0}$)	I	**INTERAGENT COMMUNICATION REQUEST/INTERRUPT 0** indicates either that there is a pending IAC message for the processor or an interrupt. The bus interrupt control register determines in which way the signal should be interpreted. To signal an interrupt or IAC request in a synchronous system, this pin (as well as the other interrupt pins) must be enabled by being deasserted for at least one bus cycle and then asserted for at least one additional bus cycle; in an asynchronous system, the pin must remain deasserted for at least two bus cycles and then be asserted for at least two more bus cycles. **LOCAL PROCESSOR NUMBER:** This signal is interpreted differently during system reset. If the signal is at a high voltage level, it indicates that this processor is a primary bus master (Local Processor Number = 0); if it is at a low voltage level, it indicates that this processor is a secondary bus master (Local Processor Number = 1).
INT_1	I	**INTERRUPT 1,** like $\overline{INT_0}$, provides direct interrupt signaling.
INT_2 (INTR)	I	**INTERRUPT 2/INTERRUPT REQUEST:** The bus control registers determines how this pin is interpreted. If INT_2, it has the same interpretation as the $\overline{INT_0}$ and INT1 pins. If INTR, it is used to receive an interrupt request from an external interrupt controller.
$\overline{INT_3}$ ($\overline{INTA}$)	I/O O.D.	**INTERRUPT 3/INTERRUPT ACKNOWLEDGE:** The bus interrupt control register determines how this pin is interpreted. If $\overline{INT_3}$, it has the same interpretation as the $\overline{INT_0}$, INT_1, and INT_2 pins. If $\overline{INTA}$, it is used as an output to control interrupt-acknowledge bus transactions. The $\overline{INTA}$ output is latched on-chip and remains valid during T_d cycles; as an output, it is open-drain.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = three state
$T_a = T_{Address}$, $T_d = T_{Data}$, $T_W = T_{Wait}$, $T_r = T_{Recovery}$, $T_i = T_{Idle}$, $T_h = T_{Hold}$

ELECTRICAL SPECIFICATIONS

Power and Grounding

The 80960MC is implemented in CHMOS III technology and has modest power requirements. Its high clock frequency and numerous output buffers (address/data, control, error and arbitration signals) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 12 V_{CC} and 13 V_{SS} pins separately feed functional units of the 80960MC.

Power and ground connections must be made to all power and ground pins of the 80960MC. On the circuit board, all V_{CC} pins must be strapped closely together, preferably on a power plane. Likewise, all V_{SS} pins should be strapped together, preferably on a ground plane.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the 80960MC. The processor can cause transient power surges when driving the L-Bus, particularly when it is connected to a large capacitive load.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the processor and decoupling capacitors as much as possible.

Connection Recommendations

For reliable operation, always connect unused inputs to an appropriate signal level. In particular, if one or more interrupt lines are not used, they should be pulled up or down to their respective deasserted states. No inputs should ever be left floating.

All open-drain outputs require a pullup device. While in some cases a simple pullup resistor will be adequate, we recommend a network of pullup and pulldown resistors biased to a valid V_{IH} ($\geq$ 3.4V) and terminated in the characteristic impedance of the circuit board. Figure 6 shows our recommendations for the resistor values for both a low and high current drive network, which assumes that the circuit board has a characteristic impedance of 100Ω. The advantage of terminating the output signals in this fashion is that it limits signal swing and reduces AC power consumption.

Characteristic Curves

Figure 7 shows the typical supply current requirements over the operating temperature range of the processor at supply voltage (V_{CC}) of 5V. Figure 8 shows the typical power supply current (I_{CC}) required by the 80960MC at various operating frequencies when measured at three input voltage (V_{CC}) levels.

Figure 9 shows the typical capacitive derating curve for the 80960MC measured from 1.5V on the system clock (CLK) to 0.8V on the falling edge and 2.0V on the rising edge of the L-Bus address/data (LAD) signals.

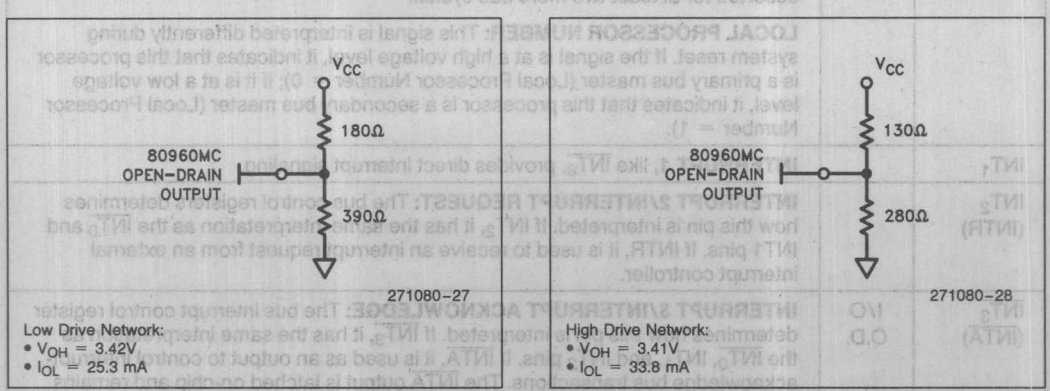


Figure 6. Connection Recommendations for Low and High Current Drive Networks

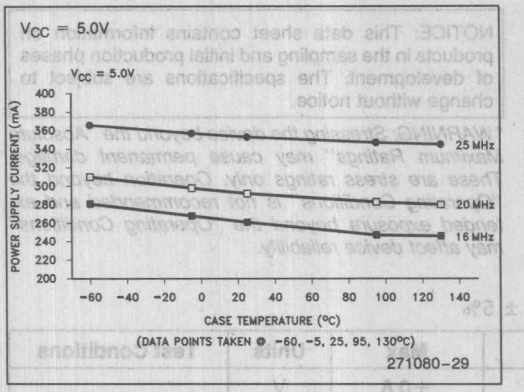


Figure 7. Typical Supply Current (I_{CC})

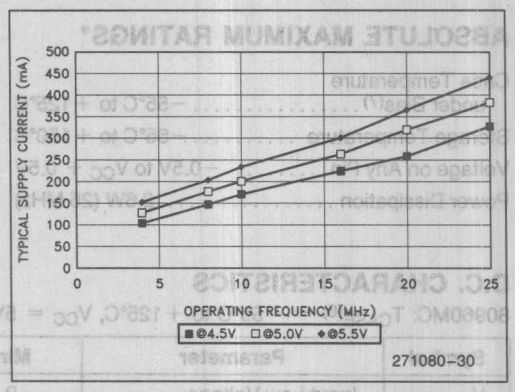


Figure 8. Typical Current vs Frequency

Test Load Circuit

Figure 10 illustrates the load circuit used to test the 80960MC's tristate pins, and Figure 11 shows the load circuit used to test the open drain outputs. The open drain test uses an active load circuit in the form of a matched diode bridge. Since the open-drain outputs sink current, only the I_{OL} legs of the bridge are necessary and the I_{OH} legs are not used. When the 80960MC driver under test is turned off, the output pin is pulled up to V_{REF} (i.e., V_{OH}). Diode D_1 is turned off and the I_{OL} current source flows through diode D_2.

When the 80960MC open-drain driver under test is on, diode D_1 is also on, and the voltage on the pin being tested drops to V_{OL}. Diode D_2 turns off and I_{OL} flows through diode D_1.

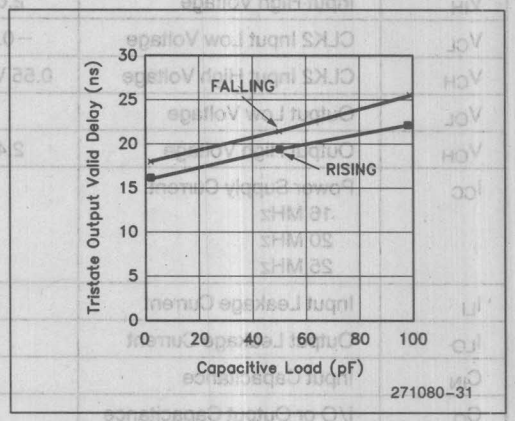


Figure 9. Capacitive Derating Curve

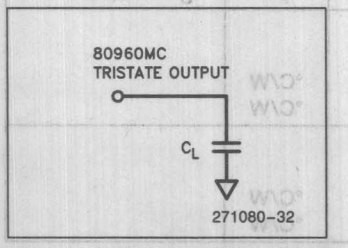


Figure 10. Test Load Circuit for TRI-STATE Output Pins

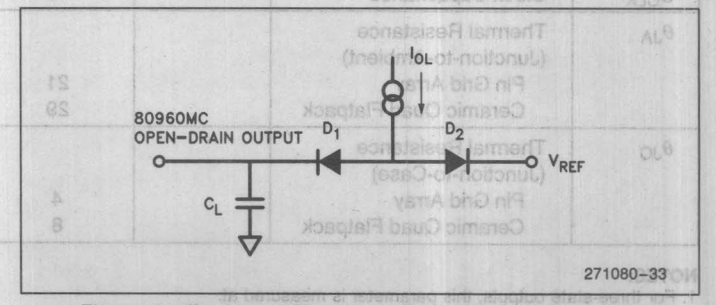


Figure 11. Test Load Circuit for Open-Drain Output Pins

ABSOLUTE MAXIMUM RATINGS*

Case Temperature under Bias(7) ..... −55°C to +125°C
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin ..... −0.5V to V_{CC} + 0.5V
Power Dissipation ..... 2.6W (25 MHz)

NOTICE: This data sheet contains information on products in the sampling and initial production phases of development. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

D.C. CHARACTERISTICS

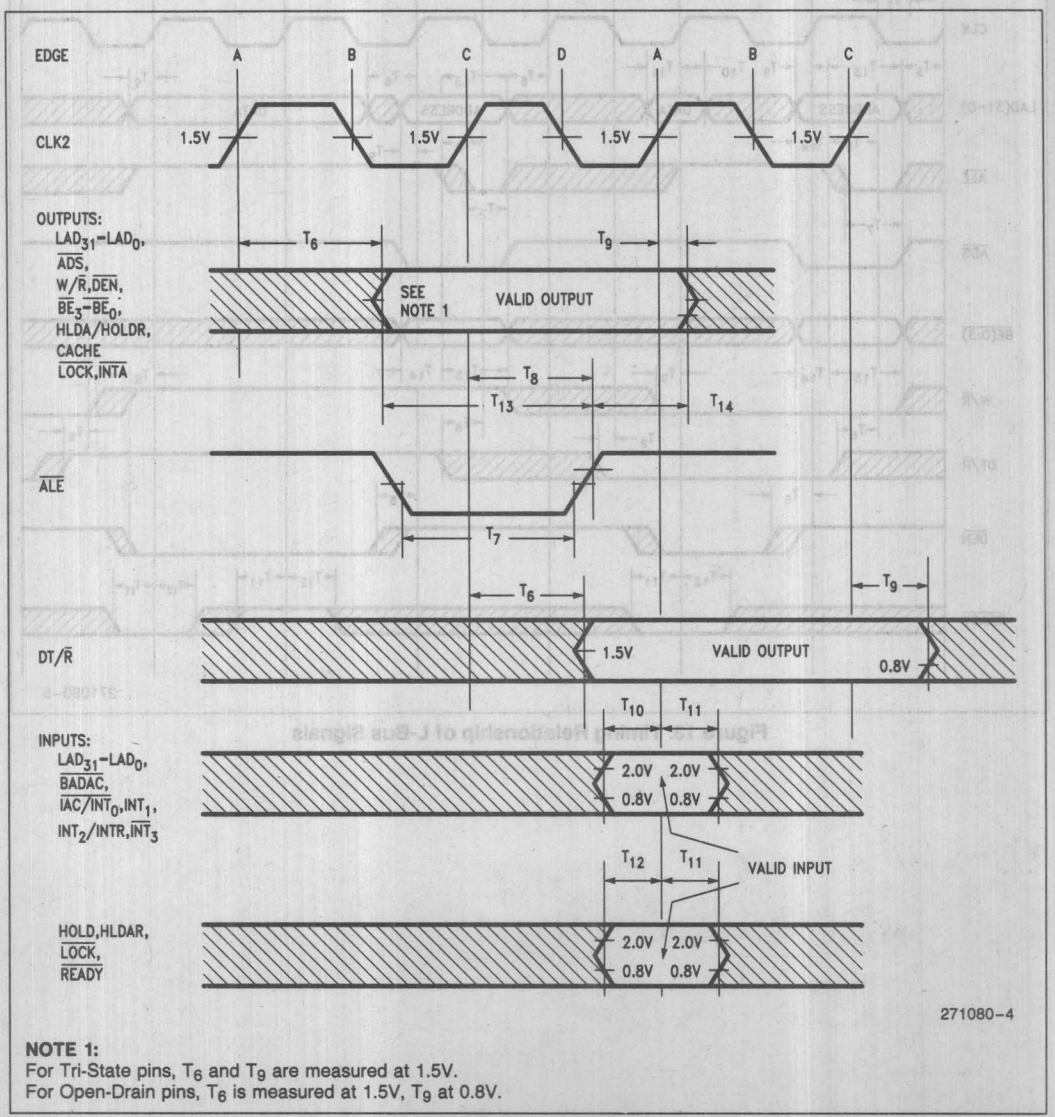
80960MC: T_{CASE}(6) = −55°C to +125°C, V_{CC} = 5V ± 5%

Symbol	Parameter	Min	Max	Units	Test Conditions
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+0.8	V	
V_{CH}	CLK2 Input High Voltage	0.55 V_{CC}	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage		0.45	V	(1, 5)
V_{OH}	Output High Voltage	2.4		V	(2, 4)
I_{CC}	Power Supply Current: 16 MHz 20 MHz 25 MHz		 375 420 480	 mA mA mA	
I_{LI}	Input Leakage Current		±15	μA	$0 \le V_O \le V_{CC}$
I_{LO}	Output Leakage Current		±15	μA	$0.45 \le V_O \le V_{CC}$
C_{IN}	Input Capacitance		10	pF	f_C = 1 MHz(3)
C_O	I/O or Output Capacitance		12	pF	f_C = 1 MHz(3)
C_{CLK}	Clock Capacitance		10	pF	f_C = 1 MHz(3)
θ_{JA}	Thermal Resistance (Junction-to-Ambient) Pin Grid Array Ceramic Quad Flatpack		 21 29	 °C/W °C/W	
θ_{JC}	Thermal Resistance (Junction-to-Case) Pin Grid Array Ceramic Quad Flatpack		 4 8	 °C/W °C/W	

NOTES:
1. For three-state outputs, this parameter is measured at:
   Address/Data ..... 4.0 mA
   Controls ..... 5.0 mA
2. This parameter is measured at:
   Address/Data ..... −1.0 mA
   Controls ..... −0.9 mA
   ALE ..... −5.0 mA
3. Input, output, and clock capacitance are not tested.
4. Not measured on open-drain outputs.
5. For open-drain outputs ..... 25 mA
6. Case temperatures are "instant on".

AC SPECIFICATIONS

This section describes the AC specifications for the 80960MC pins. All input and output timings are specified relative to the 1.5V level of the rising edge of CLK2, and refer to the time at which the signal reaches (for output delay and input setup) or leaves (for hold time) the TTL levels of LOW (0.8V) or HIGH (2.0V). All AC testing should be done with input voltages of 0.4V and 2.4V, except for the clock (CLK2), which should be tested with input voltages of 0.45V and 0.55 V_{CC}.



NOTE 1:
For Tri-State pins, T_6 and T_9 are measured at 1.5V.
For Open-Drain pins, T_6 is measured at 1.5V, T_9 at 0.8V.

Figure 12. Drive Levels and Timing Relationships for 80960MC Signals

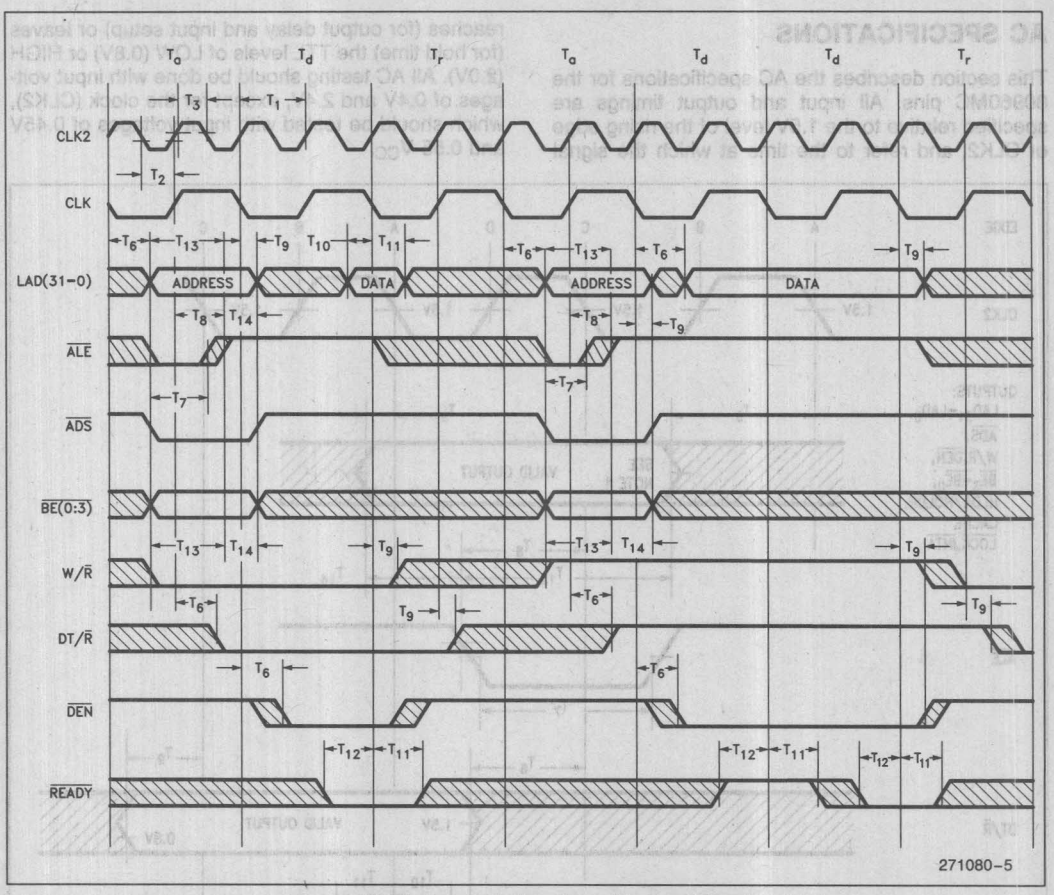


Figure 13. Timing Relationship of L-Bus Signals

A.C. Specification Tables

80960MC A.C. Characteristics (16 MHz)
T_{CASE}(3) = −55°C to +125°C, V_{CC} = 5V ±5%

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	31.25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	8		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	8		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	25	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	31	ns	C_L = 75 pF
T_7	ALE Width	15		ns	C_L = 75 pF
T_8	ALE Invalid Delay	0	20	ns	C_L = 75 pF(2)
T_9	Output Float Delay	2	20	ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)(2)
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 75 pF
T_{10}	Input Setup 1	3		ns	(Note 1)
T_{11}	Input Hold	5		ns	(Note 1)
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	8		ns	
T_{13}	Setup to ALE Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	Hold after ALE Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1281		ns	41 CLK2 Periods Minimum

NOTES:
1. IAC/INT_0, INT_1, INT_2/INTR, INT_3 can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Case temperatures are "instant on".

A.C. Specification Tables (Continued)

80960MC A.C. Characteristics (20 MHz)
T_{CASE}[3] = −55°C to +125°C, V_{CC} = 5V ±5%

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	25	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	6		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	6		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	26	ns	C_L = 50 pF
T_7	ALE Width	12		ns	C_L = 50 pF
T_8	ALE Invalid Delay	0	20	ns	C_L = 50 pF[2]
T_9	Output Float Delay	2	20	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)[2]
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	(Note 1)
T_{11}	Input Hold	5		ns	(Note 1)
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to ALE Inactive	10		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after ALE Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	1025		ns	41 CLK2 Periods Minimum

NOTES:
1. IAC/INT_0, INT_1, INT_2/INTR, INT_3 can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Case temperatures are "instant on".

A.C. Specification Tables (Continued)

80960MC A.C. Characteristics (25 MHz)
T_{CASE}[3] = −55°C to +125°C, V_{CC} = 5V ±5%

Symbol	Parameter	Min	Max	Units	Test Conditions
T_1	Processor Clock Period (CLK2)	20	125	ns	V_{IN} = 1.5V
T_2	Processor Clock Low Time (CLK2)	5		ns	V_{IL} = 10% Point = 1.2V
T_3	Processor Clock High Time (CLK2)	5		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay	2	19	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{6H}	HOLDA Output Valid Delay	4	24	ns	C_L = 50 pF
T_7	ALE Width	12		ns	C_L = 50 pF
T_8	ALE Invalid Delay	0	20	ns	C_L = 50 pF[2]
T_9	Output Float Delay	2	19	ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)[2]
T_{9H}	HOLDA Output Float Delay	4	20	ns	C_L = 50 pF
T_{10}	Input Setup 1	3		ns	(Note 1)
T_{11}	Input Hold	5		ns	(Note 1)
T_{11H}	HOLD Input Hold	4		ns	
T_{12}	Input Setup 2	7		ns	
T_{13}	Setup to ALE Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{14}	Hold after ALE Inactive	8		ns	C_L = 60 pF (LAD) C_L = 50 pF (Controls)
T_{15}	Reset Hold	3		ns	
T_{16}	Reset Setup	5		ns	
T_{17}	Reset Width	820		ns	41 CLK2 Periods Minimum

NOTES:
1. IAC/INT_0, INT_1, INT_2/INTR, INT_3 can be asynchronous.
2. A float condition occurs when the maximum output current becomes less than I_{LO}. Float delay is not tested, but should be no longer than the valid delay.
3. Case temperatures are "instant on".

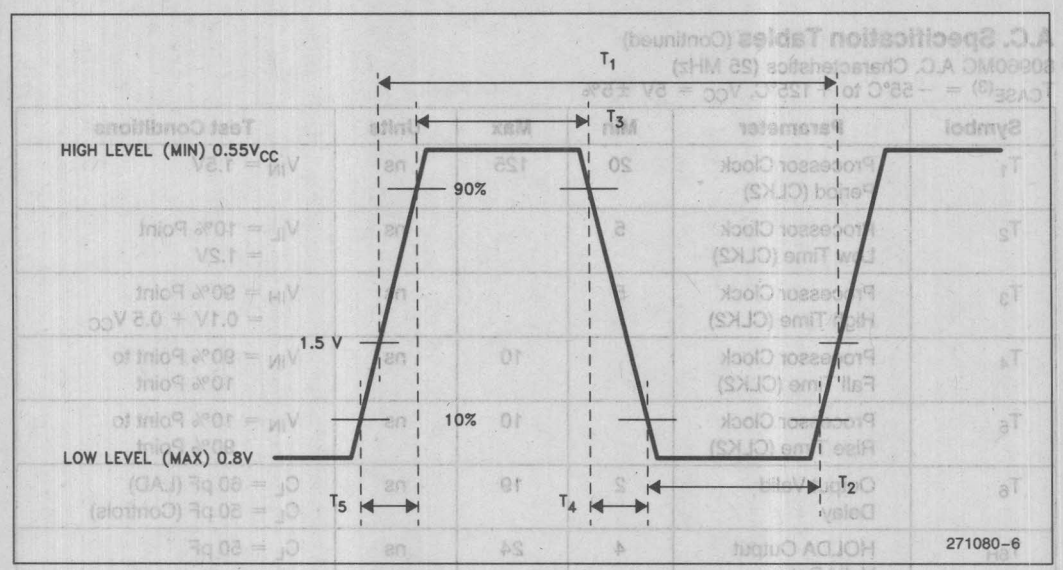


Figure 14. Processor Clock Pulse (CLK2)

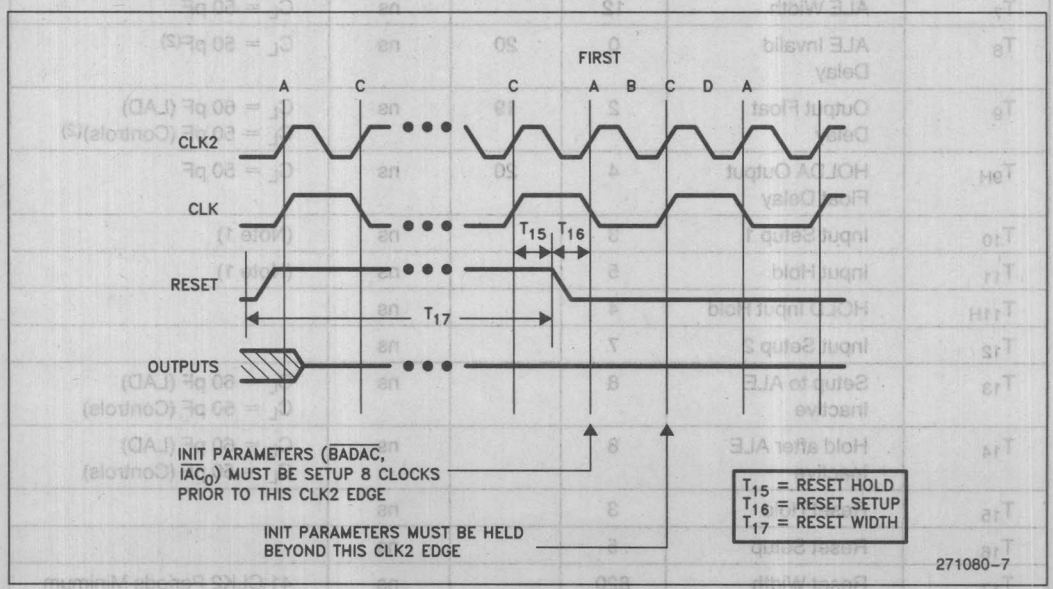


Figure 15. RESET Signal Timing

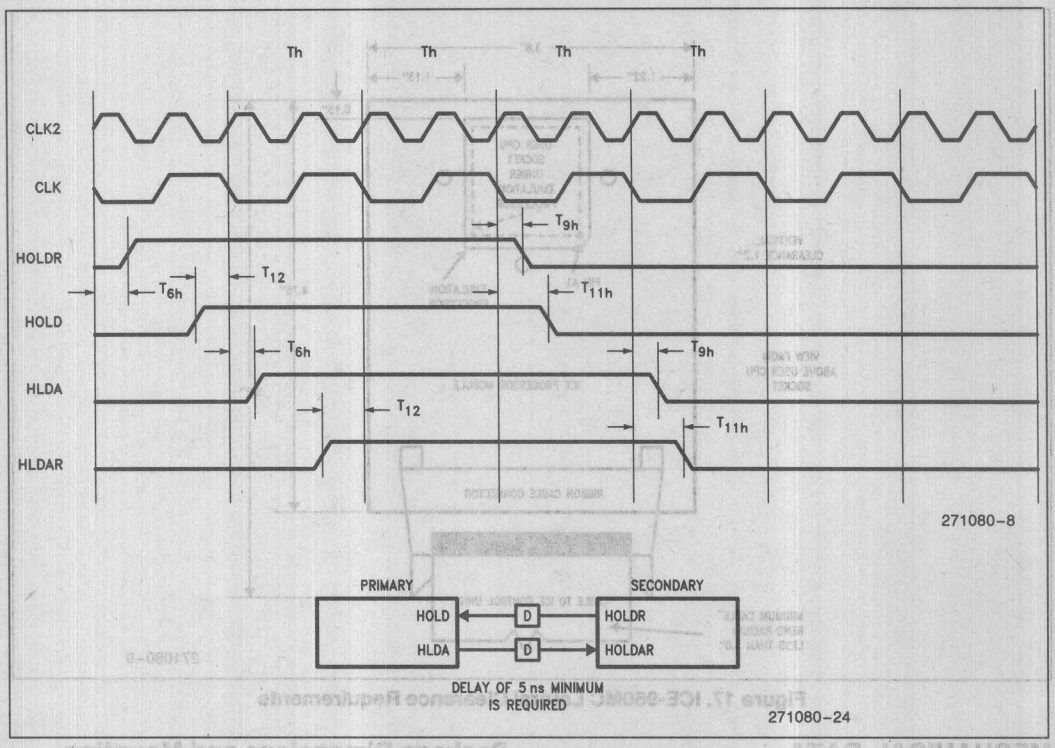


Figure 16. Hold Timing

Design Considerations

Input hold times can be disregarded by the designer whenever the input is removed because a subsequent output from the processor is deasserted (e.g., $\overline{DEN}$ becomes deasserted).

In other words, whenever the processor generates an output that indicates a transition into a subsequent state, the processor must have sampled any inputs for the previous state.

Similarly, whenever the processor generates an output that indicates a transition into a subsequent state, any outputs that are specified to be three stated in this new state are guaranteed to be three stated.

Designing for the ICE-960MC

The 80960MC In-Circuit Emulator assists in debugging 80960MC hardware and software designs. The product consists of a probe module, cable, and control unit. Because of the high operating frequency of 80960MC systems, the probe module connects directly to the 80960MC socket.

When designing an 80960MC hardware system that uses the ICE-960MC to debug the system, several electrical and mechanical characteristics should be considered. These considerations include capacitive loading, drive requirement, power requirement, and physical layout.

The ICE-960MC probe module increases the load capacitance of each line by up to 25 pF. It also adds one standard Schottky TTL load on the CLK2 line, up to one advanced low-power Schottky TTL load for each control signal line, and one advanced low-power Schottky TTL load for each address/data and byte enable line. These loads originate from the probe module and are driven by the 80960MC processor.

To achieve high noise immunity, the ICE-960MC probe is powered by the user's system. The high-speed probe circuitry draws up to 1.1A plus the maximum current (I_{CC}) of the 80960MC processor.

The mechanical considerations are shown in Figure 17, which illustrates the lateral clearance requirements for the ICE-960MC probe as viewed from above the socket of the 80960MC processor.

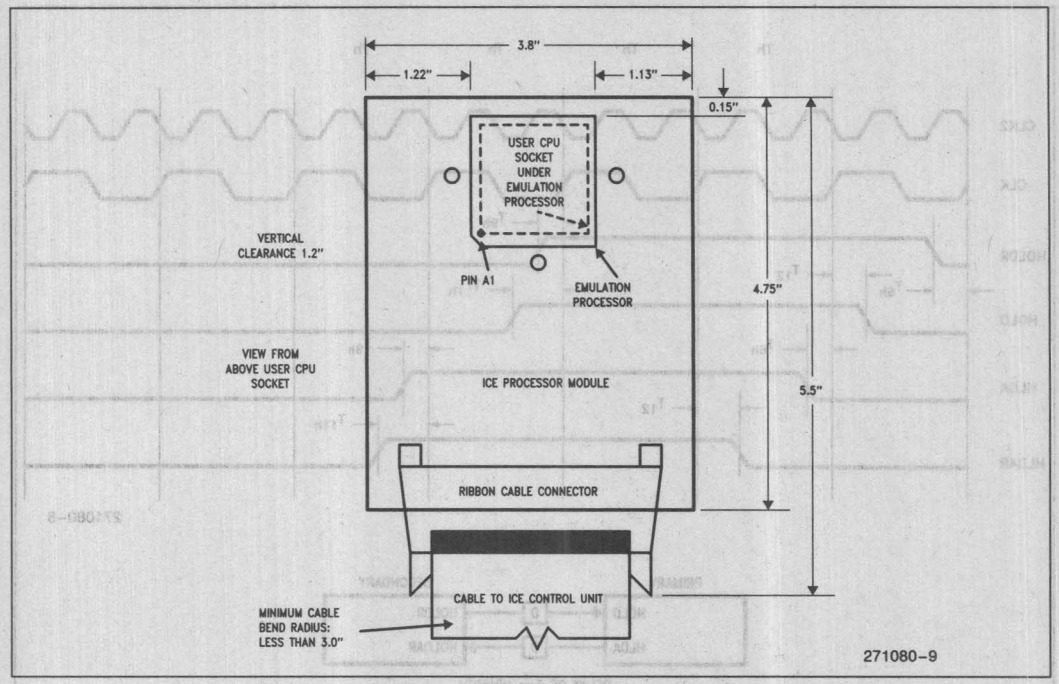


Figure 17. ICE-960MC Lateral Clearance Requirements

MECHANICAL DATA

Pin Assignment

The 80960MC is packaged in a 132-lead ceramic pin grid array and a 164-lead ceramic quad flatpack. The 80960MC pin grid array pinout as viewed from the substrate side of the component is shown in Figure 18 and from the pin side in Figure 19. The 80960MC ceramic quad flatpack pinout as viewed from the top of the package is shown in Figure 20.

V_{CC} and GND connections must be made to multiple V_{CC} and GND pins. Each V_{CC} and GND pin must be connected to the appropriate voltage or ground and externally strapped close to the package. Preferably, the circuit board should include power and ground planes for power distribution. Tables 5, 6, 7 and 8 list the function of each pin.

NOTE:
Pins identified as N.C., "No Connect," should never be connected under any circumstances.

Package Dimensions and Mounting

Pins in the pin grid array package are arranged 0.100 inch (2.54mm) center-to-center, in a 14 by 14 matrix, three rows around. (See Figure 21.)

A wide variety of available sockets allow low-insertion or zero-insertion force mountings, and a choice of terminals such as soldertail, surface mount, or wire wrap. Several applicable sockets are shown in Figure 22.

Package Thermal Specification

The 80960MC is specified for operation when its case temperature is within the range of −55°C to +125°C. The PGA case temperature should be measured at the center of the top surface opposite the pins as shown in Figure 23. The ceramic quad flatpack case temperature should be measured at the center of the lid on the top surface of the package.

WAVEFORMS

Figures 24 through 30 show the waveforms for various transactions on the 80960MC's local bus.

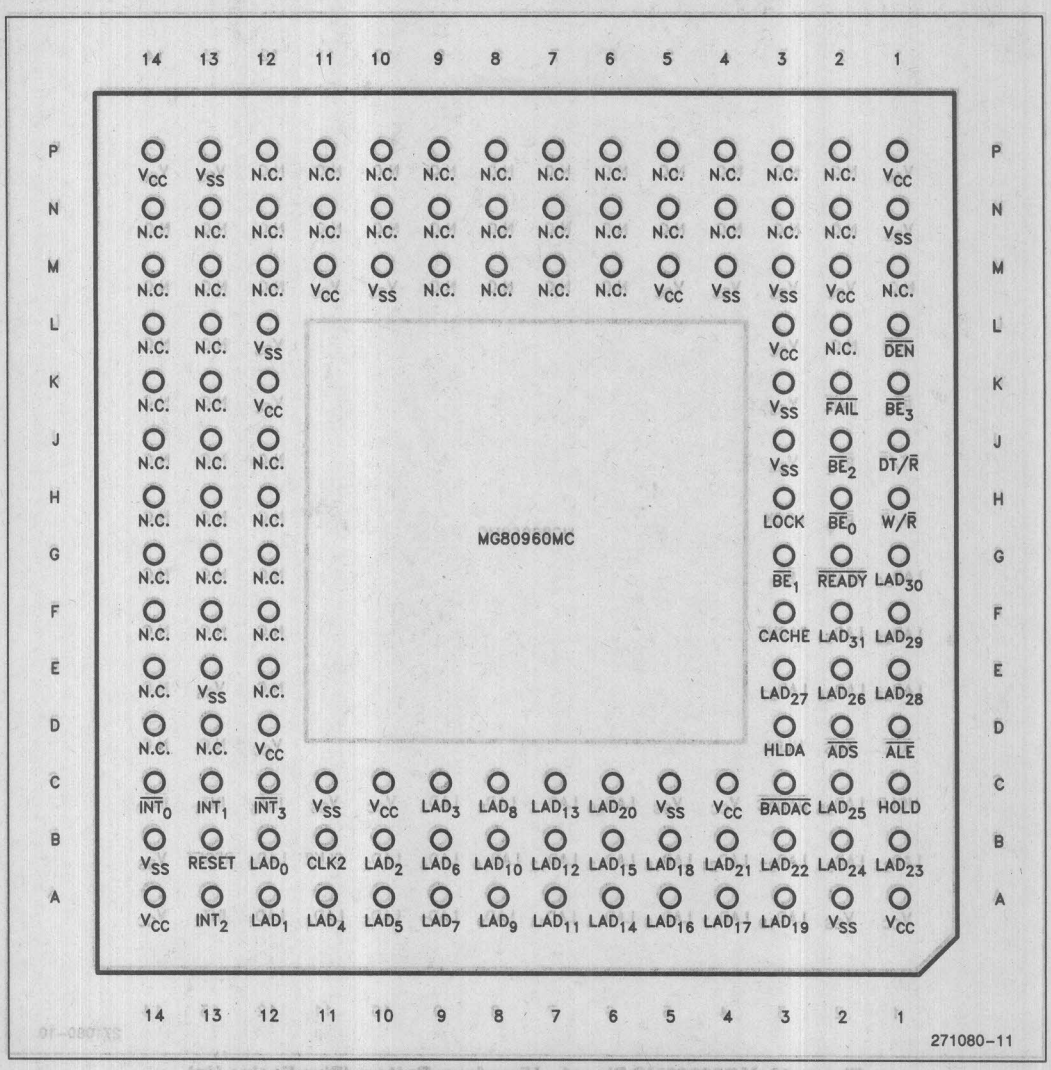


Figure 18. MG80960MC Pinout—View from Top (Pins Facing Down)

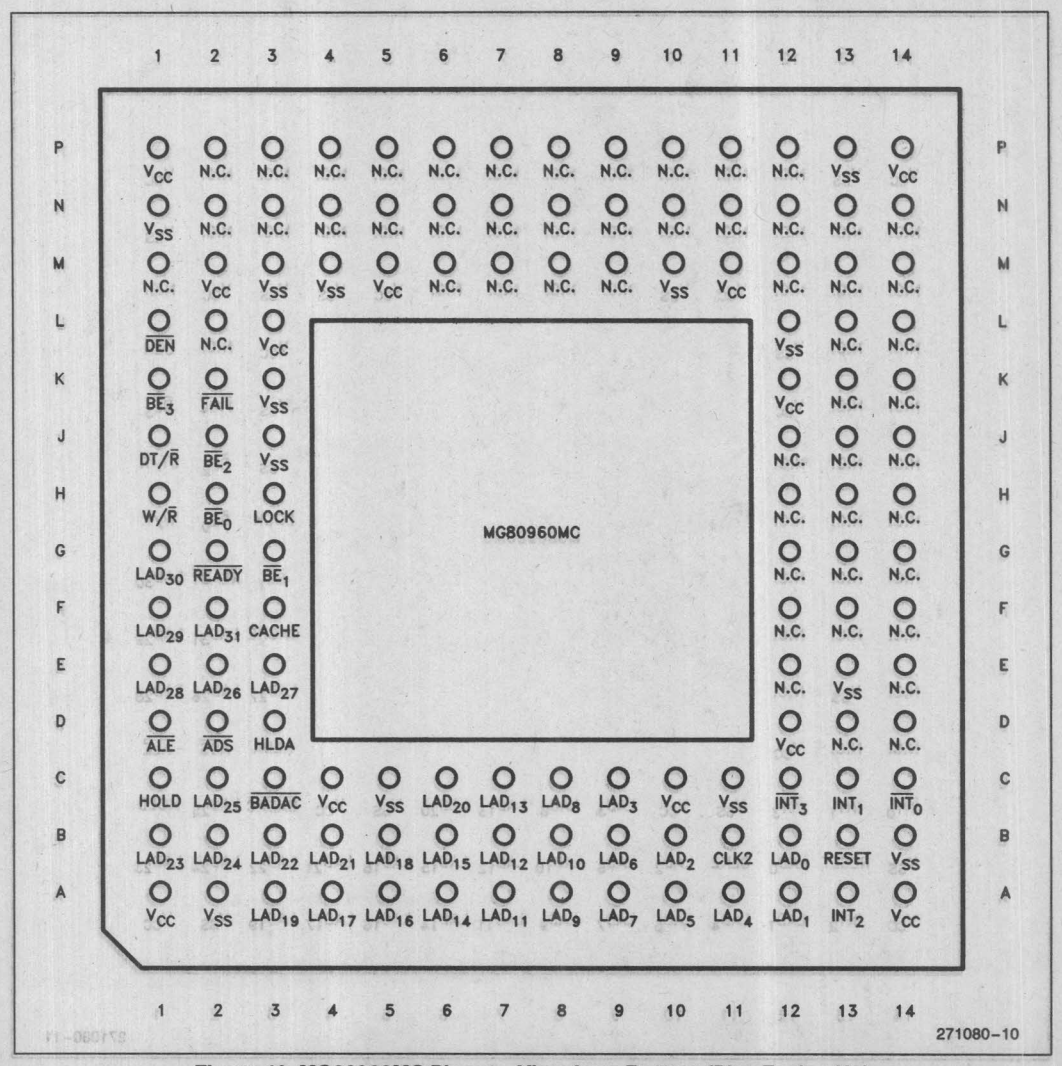
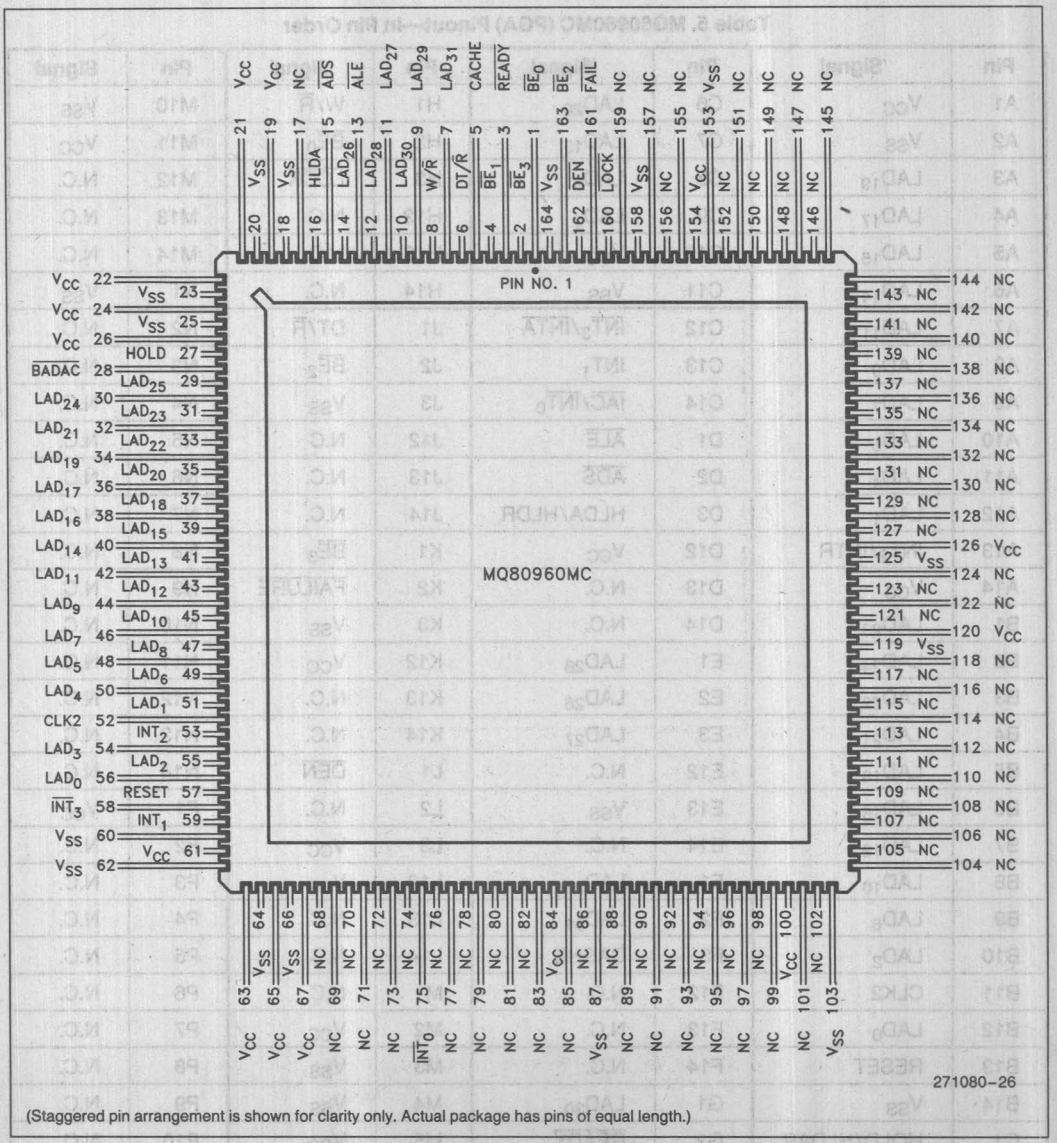


Figure 19. MG80960MC Pinout—View from Bottom (Pins Facing Up)



(Staggered pin arrangement is shown for clarity only. Actual package has pins of equal length.)

Figure 20. MQ80960MC Pinout—View from Top of Package

Table 5. MG80960MC (PGA) Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
A1	V_{CC}	C6	LAD_{20}	H1	W/$\overline{R}$	M10	V_{SS}
A2	V_{SS}	C7	LAD_{13}	H2	$\overline{BE}_0$	M11	V_{CC}
A3	LAD_{19}	C8	LAD_8	H3	$\overline{LOCK}$	M12	N.C.
A4	LAD_{17}	C9	LAD_3	H12	N.C	M13	N.C.
A5	LAD_{16}	C10	V_{CC}	H13	N.C.	M14	N.C.
A6	LAD_{14}	C11	V_{SS}	H14	N.C.	N1	V_{SS}
A7	LAD_{11}	C12	$\overline{INT}_3$/$\overline{INTA}$	J1	DT/$\overline{R}$	N2	N.C.
A8	LAD_9	C13	INT_1	J2	$\overline{BE}_2$	N3	N.C.
A9	LAD_7	C14	$\overline{IAC}$/$\overline{INT}_0$	J3	V_{SS}	N4	N.C.
A10	LAD_5	D1	$\overline{ALE}$	J12	N.C	N5	N.C.
A11	LAD_4	D2	$\overline{ADS}$	J13	N.C.	N6	N.C.
A12	LAD_1	D3	HLDA/HLDR	J14	N.C.	N7	N.C.
A13	INT_2/INTR	D12	V_{CC}	K1	$\overline{BE}_3$	N8	N.C.
A14	V_{CC}	D13	N.C.	K2	$\overline{FAILURE}$	N9	N.C.
B1	LAD_{23}	D14	N.C.	K3	V_{SS}	N10	N.C.
B2	LAD_{24}	E1	LAD_{28}	K12	V_{CC}	N11	N.C.
B3	LAD_{22}	E2	LAD_{26}	K13	N.C.	N12	N.C.
B4	LAD_{21}	E3	LAD_{27}	K14	N.C.	N13	N.C.
B5	LAD_{18}	E12	N.C.	L1	$\overline{DEN}$	N14	N.C.
B6	LAD_{15}	E13	V_{SS}	L2	N.C.	P1	V_{CC}
B7	LAD_{12}	E14	N.C.	L3	V_{CC}	P2	N.C.
B8	LAD_{10}	F1	LAD_{29}	L12	V_{SS}	P3	N.C.
B9	LAD_6	F2	LAD_{31}	L13	N.C.	P4	N.C.
B10	LAD_2	F3	CACHE	L14	N.C.	P5	N.C.
B11	CLK2	F12	N.C.	M1	N.C.	P6	N.C.
B12	LAD_0	F13	N.C.	M2	V_{CC}	P7	N.C.
B13	RESET	F14	N.C.	M3	V_{SS}	P8	N.C.
B14	V_{SS}	G1	LAD_{30}	M4	V_{SS}	P9	N.C.
C1	HOLD/HLDAR	G2	$\overline{READY}$	M5	V_{CC}	P10	N.C.
C2	LAD_{25}	G3	$\overline{BE}_1$	M6	N.C.	P11	N.C.
C3	$\overline{BADAC}$	G12	N.C.	M7	N.C.	P12	N.C.
C4	V_{CC}	G13	N.C.	M8	N.C.	P13	V_{SS}
C5	V_{SS}	G14	N.C.	M9	N.C.	P14	V_{CC}

NOTE:
Pins identified as N.C. ("No Connect") should never be connected under any circumstances.

Table 6. MG80960MC (PGA) Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	D2	LAD_{15}	B6	N.C.	J14	N.C.	P89
$\overline{ALE}$	D1	LAD_{16}	A5	N.C.	K13	N.C.	P10
$\overline{BADAC}$	C3	LAD_{17}	A4	N.C.	K14	N.C.	P11
$\overline{BE_0}$	H2	LAD_{18}	B5	N.C.	L13	N.C.	P12
$\overline{BE_1}$	G3	LAD_{19}	A3	N.C.	L14	N.C.	L2
$\overline{BE_2}$	J2	LAD_{20}	C6	N.C.	M1	N.C.	G2
$\overline{BE_3}$	K1	LAD_{21}	B4	N.C.	M6	$\overline{READY}$	B13
CACHE	F3	LAD_{22}	B3	N.C.	M7	RESET	A1
CLK2	B11	LAD_{23}	B1	N.C.	M8	V_{CC}	A14
$\overline{DEN}$	L1	LAD_{24}	B2	N.C.	M9	V_{CC}	C4
DT/$\overline{R}$	J1	LAD_{25}	C2	N.C.	M12	V_{CC}	C10
$\overline{FAILURE}$	K2	LAD_{26}	E2	N.C.	M13	V_{CC}	D12
HLDA/HOLDR	D3	LAD_{27}	E3	N.C.	M14	V_{CC}	K12
HOLD/HLDAR	C1	LAD_{28}	E1	N.C.	N2	V_{CC}	L3
$\overline{IAC}/\overline{INT_0}$	C14	LAD_{29}	F1	N.C.	N3	V_{CC}	M2
INT_1	C13	LAD_{30}	G1	N.C.	N4	V_{CC}	M5
INT_2/INTR	A13	LAD_{31}	F2	N.C.	N5	V_{CC}	M11
$\overline{INT_3}/\overline{INTA}$	C12	$\overline{LOCK}$	H3	N.C.	N6	V_{CC}	P1
LAD_0	B12	N.C.	D13	N.C.	N7	V_{CC}	P14
LAD_1	A12	N.C.	D14	N.C.	N8	V_{SS}	A2
LAD_2	B10	N.C.	E12	N.C.	N9	V_{SS}	B14
LAD_3	C9	N.C.	E14	N.C.	N10	V_{SS}	C5
LAD_4	A11	N.C.	F12	N.C.	N11	V_{SS}	C11
LAD_5	A10	N.C.	F13	N.C.	N12	V_{SS}	E13
LAD_6	B9	N.C.	F14	N.C.	N13	V_{SS}	J3
LAD_7	A9	N.C.	G12	N.C.	N14	V_{SS}	K3
LAD_8	C8	N.C.	G13	N.C.	P2	V_{SS}	L12
LAD_9	A8	N.C.	G14	N.C.	P3	V_{SS}	M3
LAD_{10}	B8	N.C.	H12	N.C.	P4	V_{SS}	M4
LAD_{11}	A7	N.C.	H13	N.C.	P5	V_{SS}	M10
LAD_{12}	B7	N.C.	H14	N.C.	P6	V_{SS}	N1
LAD_{13}	C7	N.C.	J12	N.C.	P7	V_{SS}	P13
LAD_{14}	A6	N.C.	J13	N.C.	P8	W/$\overline{R}$	H1

NOTE:
Pins identified as N.C. ("No Connect") should never be connected under any circumstances.

Table 7. MQ80960MC (CQP) Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
1	$\overline{BE_0}$	42	LAD_{11}	83	N.C.	124	N.C.
2	$\overline{BE_3}$	43	LAD_{12}	84	V_{CC}	125	V_{SS}
3	$\overline{READY}$	44	LAD_9	85	N.C.	126	V_{CC}
4	$\overline{BE_1}$	45	LAD_{10}	86	N.C.	127	N.C.
5	CACHE	46	LAD_7	87	V_{SS}	128	N.C.
6	DT/$\overline{R}$	47	LAD_8	88	N.C.	129	N.C.
7	LAD_{31}	48	LAD_5	89	N.C.	130	N.C.
8	W/$\overline{R}$	49	LAD_6	90	N.C.	131	N.C.
9	LAD_{29}	50	LAD_4	91	N.C.	132	N.C.
10	LAD_{30}	51	LAD_1	92	N.C.	133	N.C.
11	LAD_{27}	52	CLK_2	93	N.C.	134	N.C.
12	LAD_{28}	53	INT_2	94	N.C.	135	N.C.
13	$\overline{ALE}$	54	LAD_3	95	N.C.	136	N.C.
14	LAD_{26}	55	LAD_2	96	N.C.	137	N.C.
15	$\overline{ADS}$	56	LAD_0	97	N.C.	138	N.C.
16	HLDA	57	RESET	98	N.C.	139	N.C.
17	N.C.	58	$\overline{INT_3}$	99	N.C.	140	N.C.
18	V_{SS}	59	INT_1	100	V_{CC}	141	N.C.
19	V_{CC}	60	V_{SS}	101	N.C.	142	N.C.
20	V_{SS}	61	V_{CC}	102	N.C.	143	N.C.
21	V_{CC}	62	V_{SS}	103	V_{SS}	144	N.C.
22	V_{CC}	63	V_{CC}	104	N.C.	145	N.C.
23	V_{SS}	64	V_{SS}	105	N.C.	146	N.C.
24	V_{CC}	65	V_{CC}	106	N.C.	147	N.C.
25	V_{SS}	66	V_{SS}	107	N.C.	148	N.C.
26	V_{CC}	67	V_{CC}	108	N.C.	149	N.C.
27	HOLD	68	N.C.	109	N.C.	150	N.C.
28	$\overline{BADAC}$	69	N.C.	110	N.C.	151	N.C.
29	LAD_{25}	70	N.C.	111	N.C.	152	N.C.
30	LAD_{24}	71	N.C.	112	N.C.	153	V_{SS}
31	LAD_{23}	72	N.C.	113	N.C.	154	V_{CC}
32	LAD_{21}	73	N.C.	114	N.C.	155	N.C.
33	LAD_{22}	74	N.C.	115	N.C.	156	N.C.
34	LAD_{19}	75	$\overline{INT_0}$	116	N.C.	157	N.C.
35	LAD_{20}	76	N.C.	117	N.C.	158	V_{SS}
36	LAD_{17}	77	N.C.	118	N.C.	159	N.C.
37	LAD_{18}	78	N.C.	119	V_{SS}	160	$\overline{LOCK}$
38	LAD_{16}	79	N.C.	120	V_{CC}	161	$\overline{FAIL}$
39	LAD_{15}	80	N.C.	121	N.C.	162	$\overline{DEN}$
40	LAD_{14}	81	N.C.	122	N.C.	163	$\overline{BE_2}$
41	LAD_{13}	82	N.C.	123	N.C.	164	V_{SS}

NOTE:
Pins identified as N.C. ("No Connect") should never be connected under any circumstances.

Table 8. MQ80960MC (CQP) Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
$\overline{ADS}$	15	LAD_{23}	31	N.C.	102	N.C.	148
$\overline{ALE}$	13	LAD_{24}	30	N.C.	104	N.C.	149
$\overline{BADAC}$	28	LAD_{25}	29	N.C.	105	N.C.	150
$\overline{BE_0}$	1	LAD_{26}	14	N.C.	106	N.C.	151
$\overline{BE_1}$	4	LAD_{27}	11	N.C.	107	N.C.	152
$\overline{BE_2}$	163	LAD_{28}	12	N.C.	108	N.C.	155
$\overline{BE_3}$	2	LAD_{29}	9	N.C.	109	N.C.	156
CACHE	5	LAD_{30}	10	N.C.	110	N.C.	157
CLK2	52	LAD_{31}	7	N.C.	111	N.C.	159
$\overline{DEN}$	162	$\overline{LOCK}$	160	N.C.	112	$\overline{READY}$	3
$DT/\overline{R}$	6	N.C.	17	N.C.	113	RESET	57
$\overline{FAILURE}$	161	N.C.	68	N.C.	114	V_{CC}	19
HLDA/HOLDR	16	N.C.	69	N.C.	115	V_{CC}	21
HOLD/HLDAR	27	N.C.	70	N.C.	116	V_{CC}	22
$\overline{IAC}/\overline{INT_0}$	75	N.C.	71	N.C.	117	V_{CC}	24
INT_1	59	N.C.	72	N.C.	118	V_{CC}	26
INT_2/INTR	53	N.C.	73	N.C.	121	V_{CC}	61
$\overline{INT_3}/\overline{INTA}$	58	N.C.	74	N.C.	122	V_{CC}	63
LAD_0	56	N.C.	76	N.C.	123	V_{CC}	65
LAD_1	51	N.C.	77	N.C.	124	V_{CC}	67
LAD_2	55	N.C.	78	N.C.	127	V_{CC}	84
LAD_3	54	N.C.	79	N.C.	128	V_{CC}	100
LAD_4	50	N.C.	80	N.C.	129	V_{CC}	120
LAD_5	48	N.C.	81	N.C.	130	V_{CC}	126
LAD_6	49	N.C.	82	N.C.	131	V_{CC}	154
LAD_7	46	N.C.	83	N.C.	132	V_{SS}	18
LAD_8	47	N.C.	85	N.C.	133	V_{SS}	20
LAD_9	44	N.C.	86	N.C.	134	V_{SS}	23
LAD_{10}	45	N.C.	88	N.C.	135	V_{SS}	25
LAD_{11}	42	N.C.	89	N.C.	136	V_{SS}	60
LAD_{12}	43	N.C.	90	N.C.	137	V_{SS}	62
LAD_{13}	41	N.C.	91	N.C.	138	V_{SS}	64
LAD_{14}	40	N.C.	92	N.C.	139	V_{SS}	66
LAD_{15}	39	N.C.	93	N.C.	140	V_{SS}	87
LAD_{16}	38	N.C.	94	N.C.	141	V_{SS}	103
LAD_{17}	36	N.C.	95	N.C.	142	V_{SS}	119
LAD_{18}	37	N.C.	96	N.C.	143	V_{SS}	125
LAD_{19}	34	N.C.	97	N.C.	144	V_{SS}	153
LAD_{20}	35	N.C.	98	N.C.	145	V_{SS}	158
LAD_{21}	32	N.C.	99	N.C.	146	V_{SS}	164
LAD_{22}	33	N.C.	101	N.C.	147	$W/\overline{R}$	8

NOTE:
Pins identified as N.C. ("No Connect") should never be connected under any circumstances.

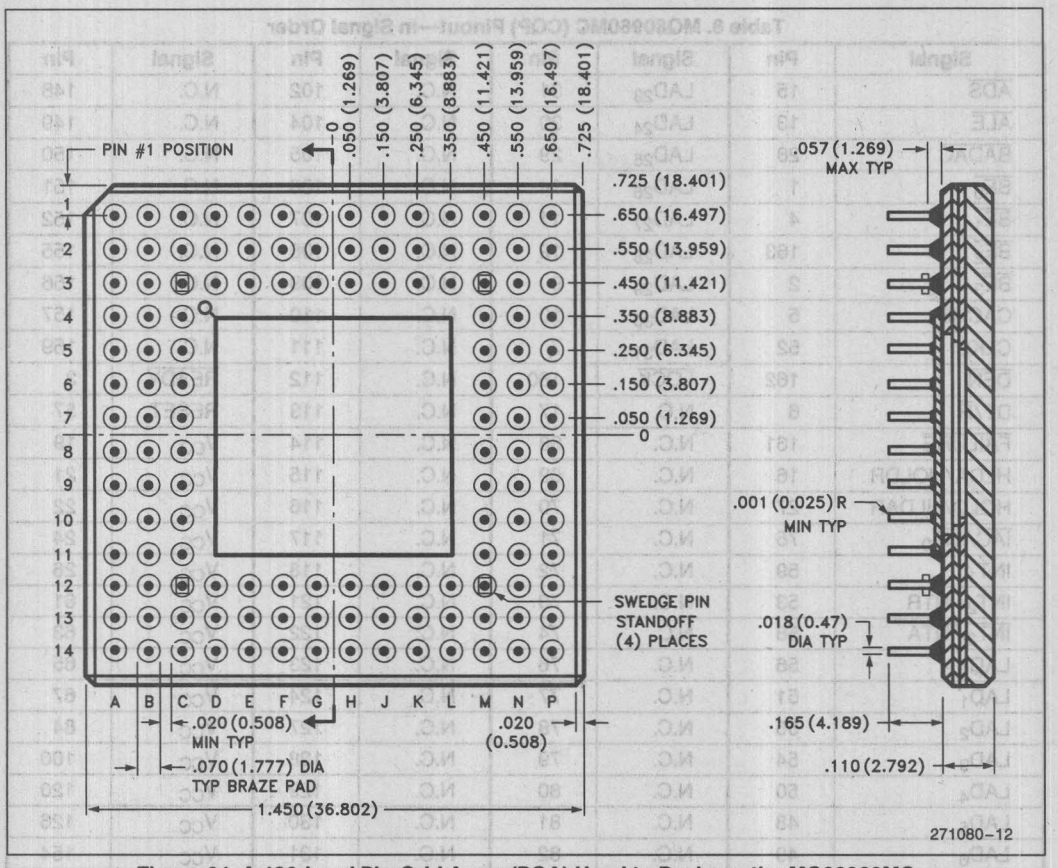


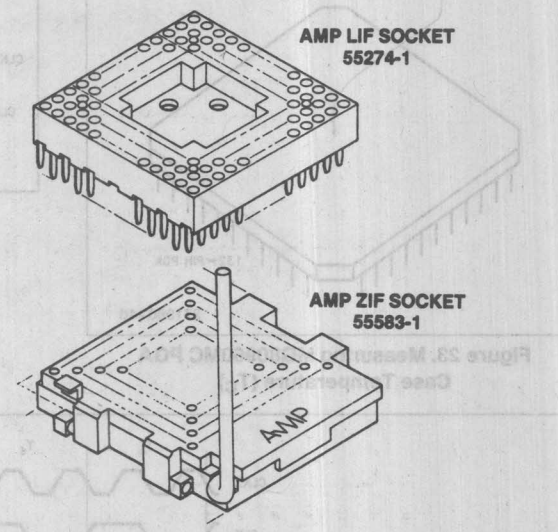
Figure 21. A 132-Lead Pin-Grid Array (PGA) Used to Package the MG80960MC

- Low insertion force (LIF) soldertail 55274-1
- Amp tests indicate 50% reduction in insertion force compared to machined sockets

Other socket options

- Zero insertion force (ZIF) soldertail 55583-1
- Zero insertion force (ZIF) Burn-in version 55573-2

Amp Incorporated
(Harrisburg, PA 17105 U.S.A
Phone 717-564-0100)



271080-13

Cam handle locks in low profile position when MG80960MC is installed (handle UP for open and DOWN for closed positions).

Courtesy Amp Incorporated

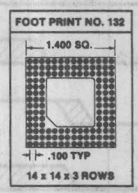
Peel-A-Way* Mylar and Kapton Socket Terminal Carriers

- Low insertion force surface mount CS132-37TG
- Low insertion force soldertail CS132-01TG
- Low insertion force wire-wrap CS132-02TG (two-level) CS132-03TG (thee-level)
- Low insertion force press-fit CS132-05TG

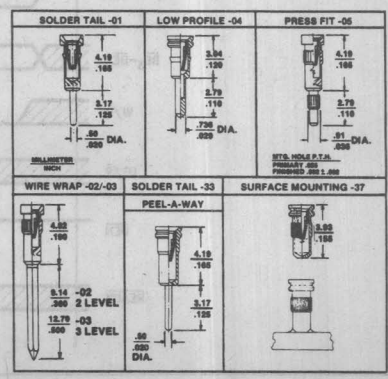
Advanced Interconnections
(5 Division Street)
Warwick, RI 02818 U.S.A.
Phone 401-885-0485)

Peel-A-Way Carrier No. 132:
Kapton Carrier is KS132
Mylar Carrier is MS132

Molded Plastic Body KS132 is shown below:



271080-14



271080-15

Courtesy Advanced Interconnections
(Peel-A-Way Terminal Carriers
U.S. Patent No. 4442938)

*Peel-A-Way is a trademark of Advanced Interconnections.

Figure 22. Several Socket Options for Mounting the MG80960MC

5

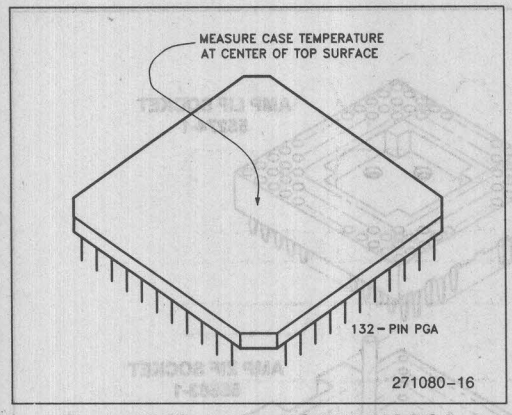


Figure 23. Measuring MG80960MC PGA Case Temperature (T_C)

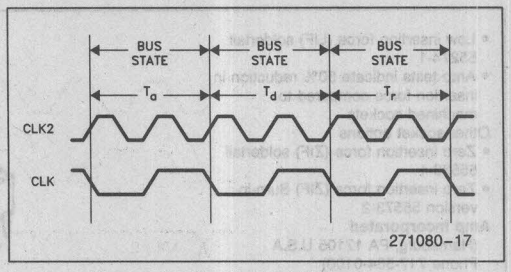


Figure 24. System and Processor Clock Relationship

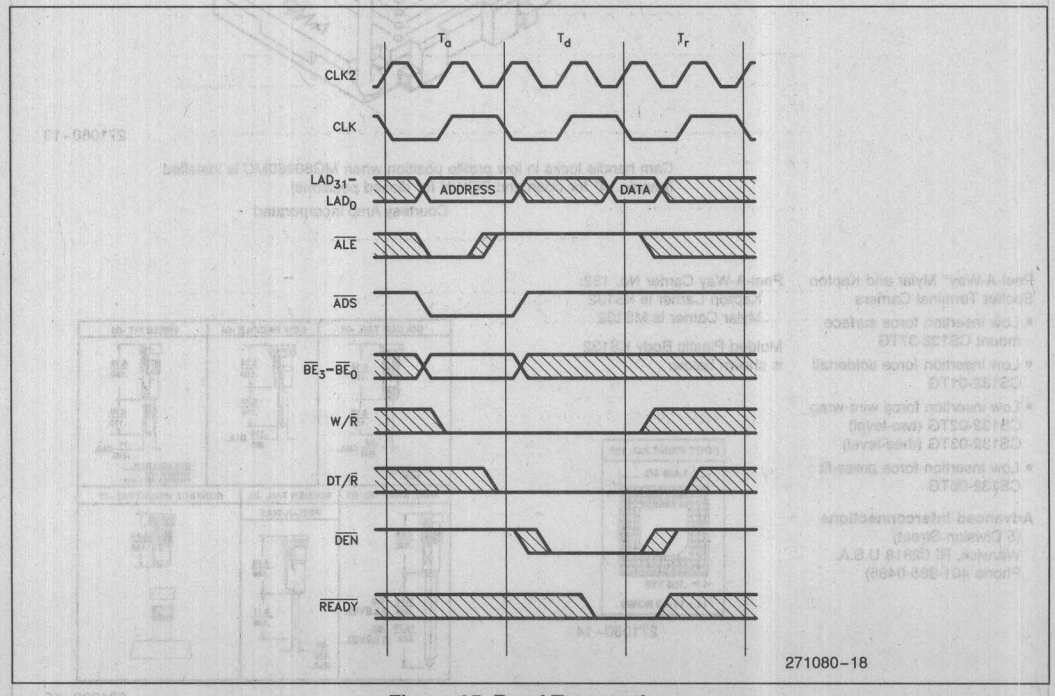


Figure 25. Read Transaction

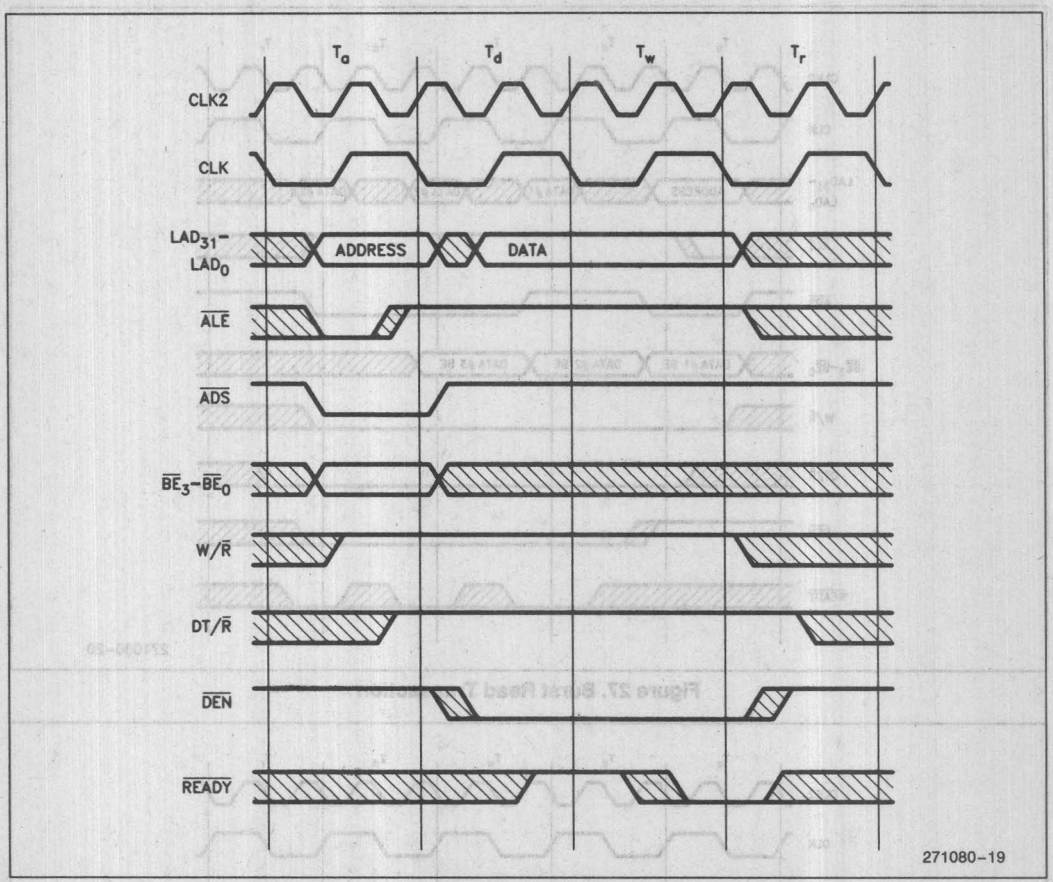


Figure 26. Write Transaction with One Wait State

5

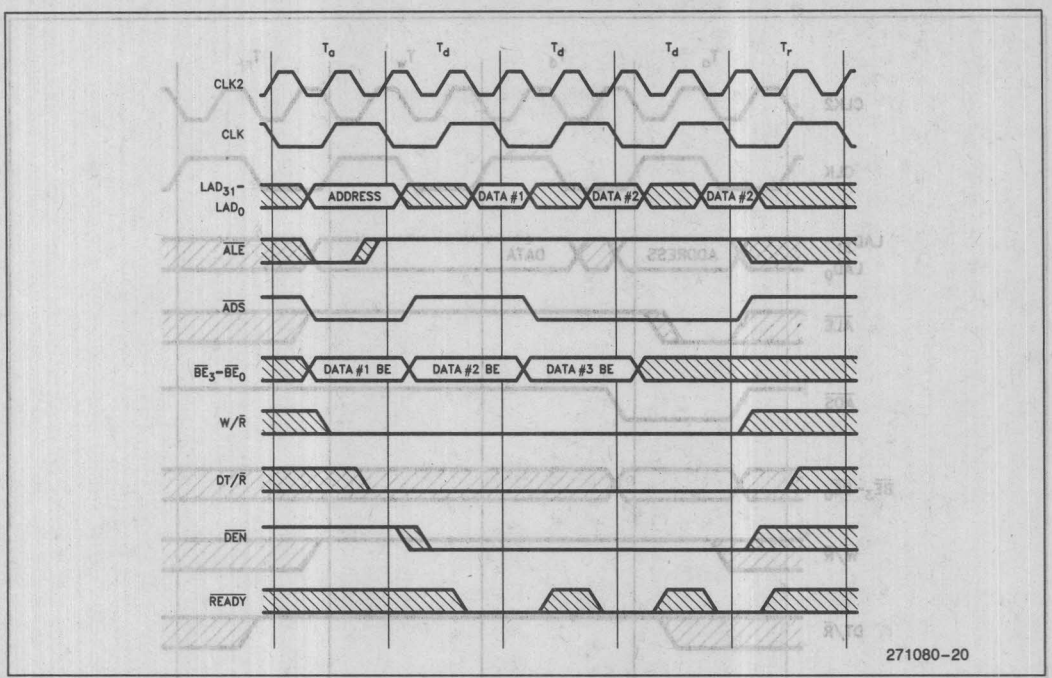


Figure 27. Burst Read Transaction

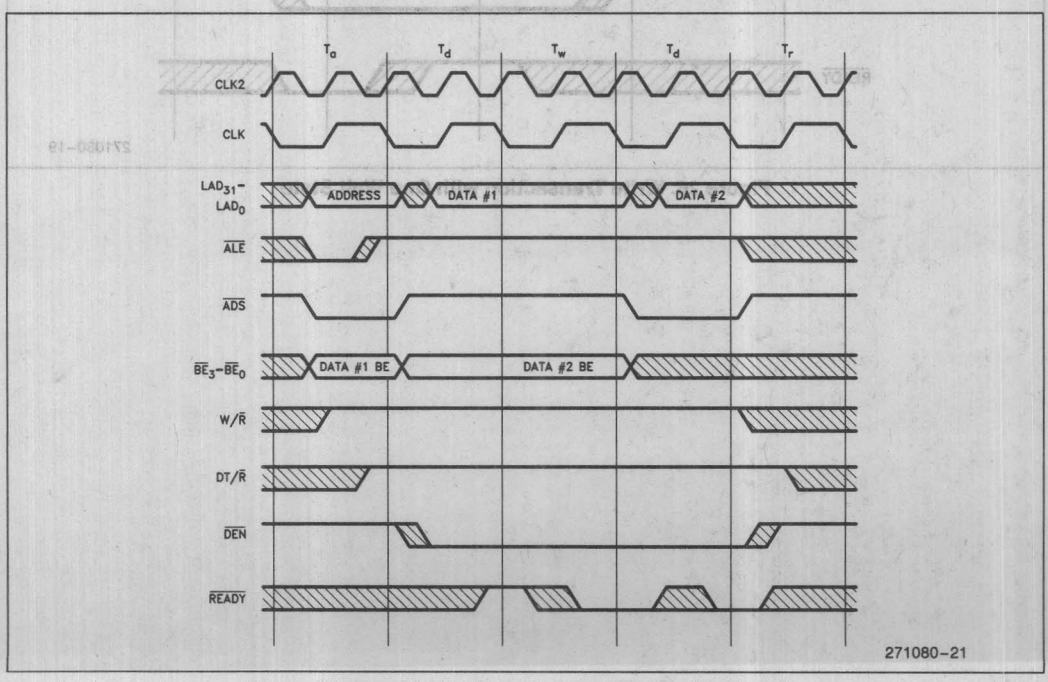


Figure 28. Burst Write Transaction with One Wait State

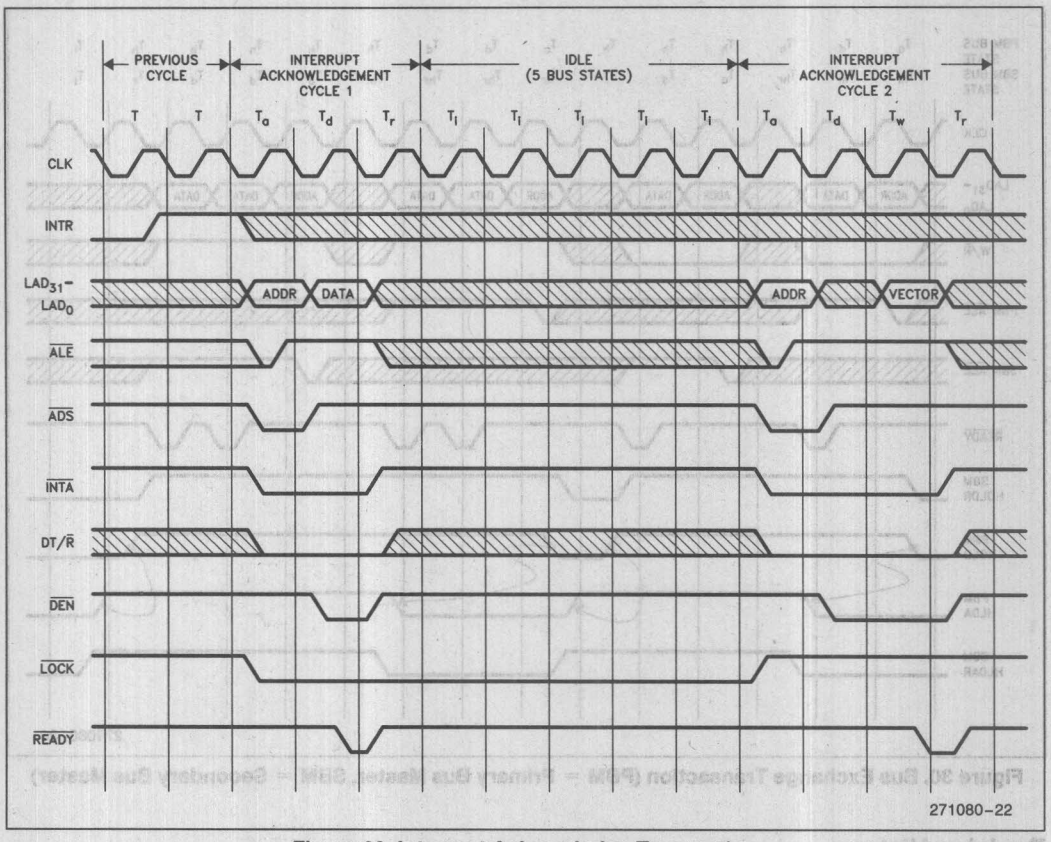


Figure 29. Interrupt Acknowledge Transaction

5

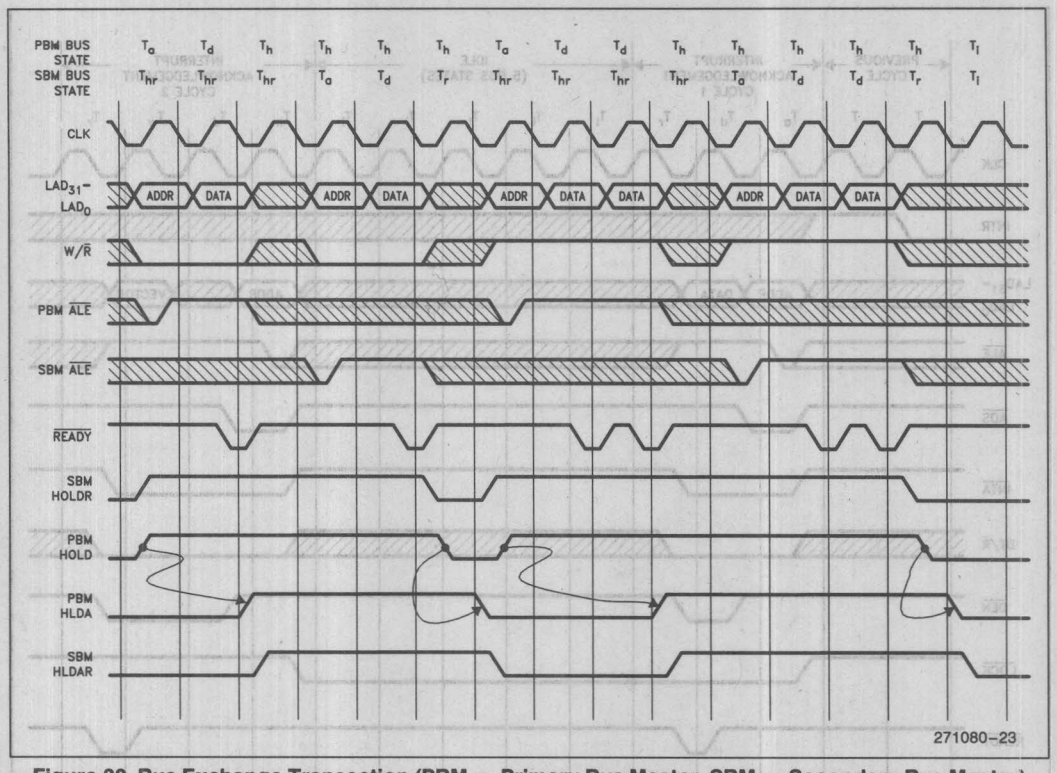


Figure 30. Bus Exchange Transaction (PBM = Primary Bus Master, SBM = Secondary Bus Master)

Revision History

1. 20 MHz timing specifications were added.
2. Pin 158, ceramic quad pack, (see Figure 20) changed from NC (No Connect) to V_{SS}.

M82965
FAULT TOLERANT BUS EXTENSION UNIT

Military

- **Multiprocessor Support**
  - **Connect up to 32 Processor and Memory Modules in a Single System**
- **Multiple Bus Support with No External Logic**
  - **Connect up to Four 32-Bit Buses for High-Bandwidth Access to Interleaved Memory**
- **Software-Transparent Fault Tolerance**
  - **Recover from a Single-Point Failure in a Module or Bus without Affecting Program Execution**
- **Cache Control Support**
  - **Provides Directory, Coherency Logic, and Control Signals for a Two-Way Set-Associative Cache**
  - **Single BXU Supports 16 Kbytes**
  - **Combine up to Four BXUs to Support 64 Kbytes**
- **Message Passing**
  - **Supports Interagent Communication**
  - **Redundant Error Reporting Network**
- **Two I/O Prefetch Channels**
  - **Provides High-Bandwidth, Low Latency Access to Memory or I/O for Sequential Transfers**
- **Memory Module Support**
  - **Interfaces Discrete Memory Controller and DRAM Array to AP-Bus**
- **Advanced CHMOS III Technology**
- **Advanced Package Technology**
  - **132 Lead Ceramic Pin Grid Array**
  - **164 Lead Ceramic Quad Flatpack**
- **Military Temperature Range: −55°C to +125°C (T_C)**

The M82965 Bus Extension Unit (BXU) is the key to building multiprocessor and fault-tolerant systems with the 80960MC 32-bit microprocessor. BXUs connect to each other in an expandable matrix that can support up to 32 processor and memory modules in a single, high-performance system. No external interface logic is required. The BXU increases overall system performance by providing hardware support for local caches, I/O prefetch, message passing, and multiprocessor arbitration. Through redundant modules, fault-tolerant systems based on the BXU can sustain a single-point failure and then reconfigure themselves automatically, while application programs continue undisrupted. Truly a VLSI building block, the M82965 BXU supports a wide range of fault tolerance and performance options to meet a diverse set of cost, performance, and reliability needs.

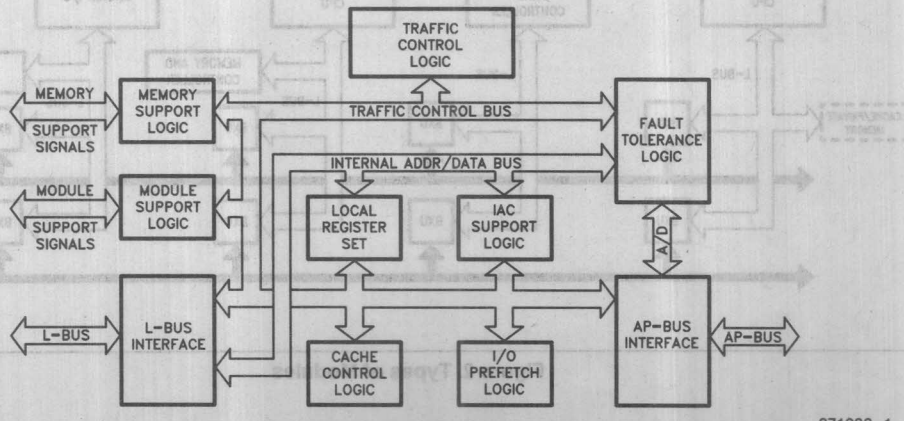


Figure 1. M82965 Block Diagram

January 1990
Order Number: 271082-003

FUNCTIONAL OVERVIEW

The M82965 Bus Extension Unit (BXU) is the key component in building multiprocessor and fault-tolerant system designs with the 80960MC 32-bit microprocessor. Its primary function is to connect the Local bus (L-Bus) of a system module to a system-wide bus called the Advanced Processor Bus (AP-Bus), allowing the system to expand incrementally as each new module or AP-Bus is added.

Several important features are provided within the BXU which streamline 80960MC multiprocessor system operation. To increase the available system bus bandwidth, multiple BXUs can be employed within each system module to support up to four AP-Buses. To reduce AP-Bus traffic, BXU components can directly support a two-way set-associative cache. I/O prefetch channels are incorporated within each BXU to reduce the time necessary to transfer large blocks of data from shared system memory or I/O. BXUs support processor-to-processor communication by recognizing, storing, and exchanging Interagent Communication (IAC) messages with other BXUs along the AP-Bus. Requests for access to the AP-Bus are resolved through BXU arbitration logic which ensures that no system modules will suffer from resource starvation.

BXUs support fault tolerant system operation through several mechanisms used to detect, isolate and recover from hardware errors. Paired BXUs monitor each other's operation on a cycle-by-cycle basis through a method called Functional Redundancy Checking (FRC). Errors on the AP-Bus are detected through interlaced parity bits on the address/data and control lines, signal duplication on the transaction control lines, and a bus timer used to monitor the bus for non-response to a request. Recovery mechanisms include the capability to marry FRC modules in a primary-shadow pair (Quad Modular Redundancy), so that if either fails, the surviving spouse can take over operations immediately. Transient errors on the AP-Bus are automatically retried, and in the case of permanent errors, the failed bus is disabled and all memory accesses switched to a backup bus.

MULTIPROCESSOR SUPPORT

A multiprocessor 80960MC system is composed of a set of modules connected to an AP-Bus. Figure 2 shows the three possible types of modules: active, passive, and the combination of both an active and passive module. Active modules contain up to two 80960MC processors, cache or private memory, and a BXU. Passive modules contain a memory array and controller and a BXU. Active/Passive modules contain either processors and global memory, or master and slave I/O devices.

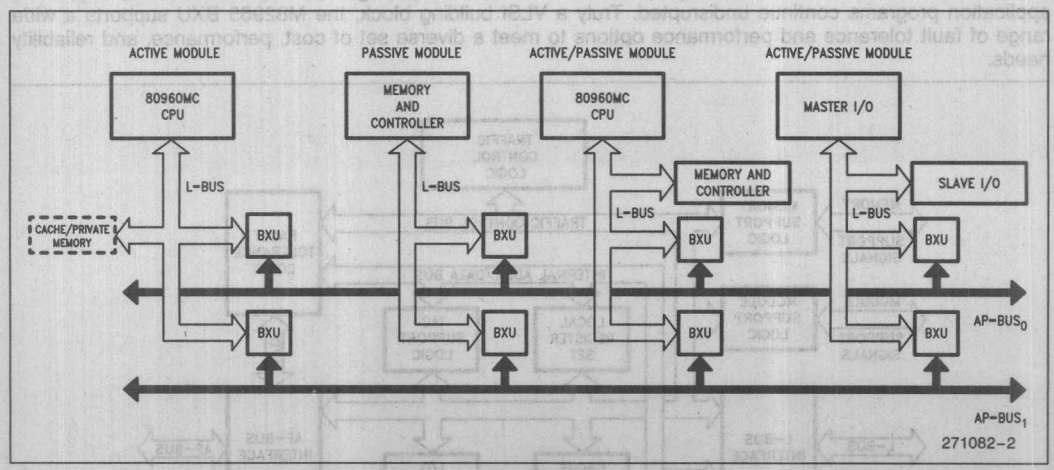


Figure 2. Types of Modules

Local Bus

In a multiprocessor system each module has its own Local Bus (L-Bus), which is typically confined to a single board. The L-Bus is provided to interconnect components within a module. It is a 32-bit multiplexed, synchronous bus with a maximum bandwidth of 43 Mbytes per second at 16 MHz. It has been designed to interface with standard support components using minimal glue logic. The L-Bus uses HOLD/HOLDA for arbitration with bus slaves and LOCK for signaling indivisible operations. A READY signal can be used to lengthen bus transactions.

Local Bus protocol permits both primary and secondary bus masters to coexist on the bus (often a processor and a DMA, or occasionally two processors). A secondary bus master must obtain use of the L-Bus from the bus master through the use of HOLDR/HOLDAR. A BXU is always used as a master in a memory module and is generally used as a slave in a processor module. Fifty BXU pins are dedicated to L-Bus and module support operations (including cache control). The L-Bus control registers are shown in Table 1.

Table 1. L-Bus Control Registers

Register	Description
Physical-ID (Local)	This register contains a unique identifier for a specific BXU on the L-Bus. It corresponds to the AP-Bus Physical-ID register.
Logical-ID (Local)	This register holds the Logical-ID of the BXU. It corresponds to the AP-Bus Logical-ID register.
LBI Control	This is the major control register for BXU functions on the L-Bus. It is used to set the interleaving factor for the cache, determines if the BXU should act as a master on the L-Bus, and indicates whether the BXU is in memory or processor mode.
System Bus ID	This register uniquely identifies the BXU as attached to one of four AP-Buses.
Local-Bus Test	This register allows system diagnostics to check on the type of recognition that was done on the previous L-Bus request.
Match 0	The contents of this register determine which bits in the L-Bus address should be recognized by the BXU. This register provides a base address for a partition of memory recognized by the BXU.
Mask 0	The contents of this register determine if certain bits in the Match 0 register should be ignored (i.e., marked "don't care") during address recognition.
Match 1	Same function as Match Register 0.
Mask 1	Same function as Mask Register 0.
Match 2	Same function as Match Register 0.
Mask 2	Same function as Mask Register 0.
Private Memory Match	Private memory address recognizer.
Private Memory Mask	Private memory mask register.

Advanced Processor Bus

A highly optimized multiprocessing bus called the Advanced Processor Bus (AP-Bus) interconnects 80960MC system modules. The AP-Bus is synchronous, in that all components in the system, including processors and BXUs, are driven by the same clock edge. It is a 32-bit multiplexed bus with a maximum bandwidth of 43 Mbytes per second at 16 MHz.

Transactions over the AP-Bus are encoded into pairs of request and reply packets. A request packet defines the operation, amount of data, and the location (or address) where the transaction will occur. In the case of a write request, the packet will also include data. The reply packet indicates whether or not the action completed successfully, and in the case of read replies, will also include the requested data. Table 2 lists the various types of AP-Bus operations.

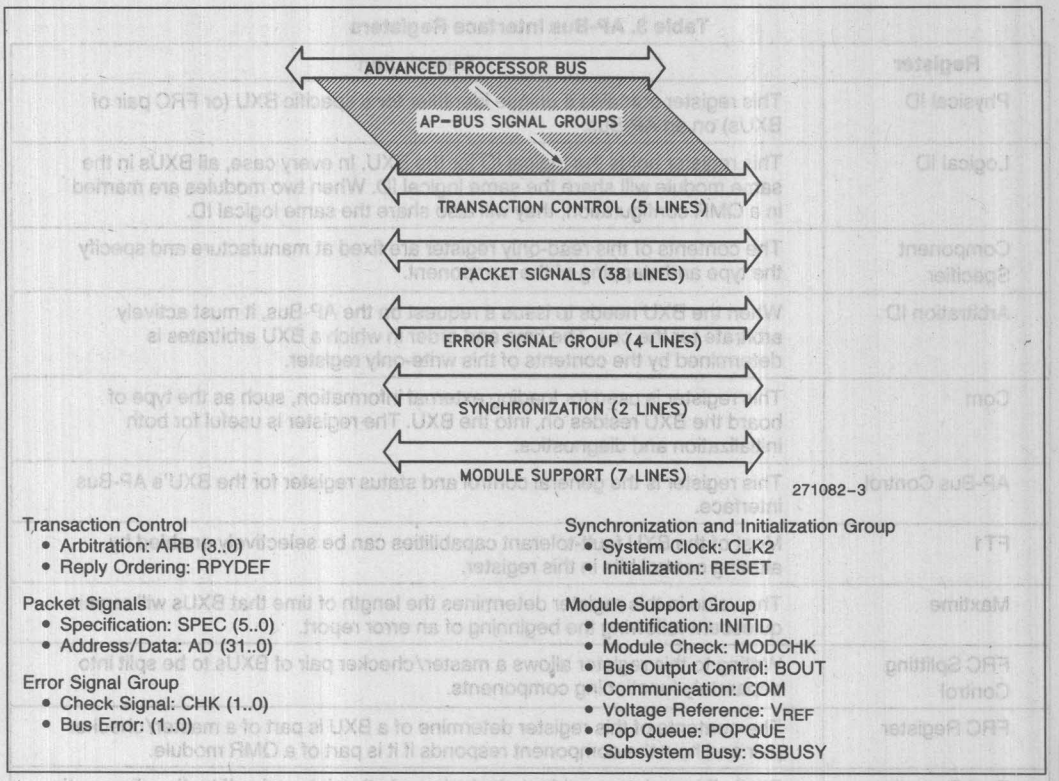
The AP-Bus supports a pipelining feature that allows up to three requests to be pending at any time. Reply packets are returned in the order requested unless deferred, but requests and replies may be intermixed. For example, two requests may be made, followed by a single reply packet, then another request packet, before being completed by two reply packets.

The AP-Bus consists of 47 bi-directional signals, a clock signal, a RESET signal, and five module support signals which are used to interface system modules to the AP-Bus (see Figure 3). The BXU is the only component that attaches to the AP-Bus.

BXUs connect to each other in the form of a matrix to allow orderly growth in the system by the addition of buses or modules. An 80960MC multiprocessing system allows up to 32 modules and four AP-Buses. In practice, the number of modules in a system will be somewhat less in order to meet the AP-Bus's timing and electrical specifications; a practical limit may be 20 to 25 connections to an AP-Bus. Table 3 contains a summary of the functions of the AP-Bus Interface Registers.

Table 2. Types of AP-Bus Operations

Packet Type	Base Action	Specific Operation
Request	Write	Write Word(s)
		RMW Write Word(s)
	Read	Read Word(s)
		RMW Read Word(s)
Reply	Accepted	Read Reply Word(s)
		Acknowledge (Write Reply)
	Refused	Reissue
		Not Acknowledged (NACK)
		Bad Access



Transaction Control
- Arbitration: ARB (3..0)
- Reply Ordering: RPYDEF

Packet Signals
- Specification: SPEC (5..0)
- Address/Data: AD (31..0)

Error Signal Group
- Check Signal: CHK (1..0)
- Bus Error: (1..0)

Synchronization and Initialization Group
- System Clock: CLK2
- Initialization: RESET

Module Support Group
- Identification: INITID
- Module Check: MODCHK
- Bus Output Control: BOUT
- Communication: COM
- Voltage Reference: V_{REF}
- Pop Queue: POPQUE
- Subsystem Busy: SSBUSY

Figure 3. Advanced Processor Bus

5

Table 3. AP-Bus Interface Registers

Register	Description
Physical ID	This register contains a unique identifier for a specific BXU (or FRC pair of BXUs) on an AP-Bus.
Logical ID	This register holds the logical ID for the BXU. In every case, all BXUs in the same module will share the same logical ID. When two modules are married in a QMR configuration, they will also share the same logical ID.
Component Specifier	The contents of this read-only register are fixed at manufacture and specify the type and stepping of the component.
Arbitration ID	When the BXU needs to issue a request on the AP-Bus, it must actively arbitrate for the bus. The time and order in which a BXU arbitrates is determined by the contents of this write-only register.
Com	This register is used for loading external information, such as the type of board the BXU resides on, into the BXU. The register is useful for both initialization and diagnostics.
AP-Bus Control	This register is the general control and status register for the BXU's AP-Bus interface.
FT1	Most of the BXU fault-tolerant capabilities can be selectively enabled by altering control bits in this register.
Maxtime	The value in this register determines the length of time that BXUs will remain quiescent following the beginning of an error report.
FRC Splitting Control	Writing to this register allows a master/checker pair of BXUs to be split into separately functioning components.
FRC Register	The contents of this register determine of a BXU is part of a master/checker pair and how the component responds if it is part of a QMR module.
Test Detection	Bits in this register enable parity logic and other internal self testing diagnostic features.
AP Match	Bits in this register are compared against the corresponding bits in the AP-Bus address cycle and determine which partition of the address space is recognized by this BXU.
AP Mask	If a bit in this register is cleared, it will cause the corresponding bit position in the Address Match register to be ignored during comparisons.

Memory addressing over the AP-Bus is divided into 16-byte blocks. The location of a bus transaction is defined by a 32-bit address. Each address points to a single byte that is part of a larger 16-byte block. All transactions are performed on a single block or portion of a block, and do not overlap multiple blocks.

Modes of Operation

The BXU operates in either Processor or Memory mode. Processor mode provides support for Active or Active/Passive modules, while Memory mode supports Passive modules. The functions of several BXU signals are dependent on the operating mode of the BXU.

In Processor mode, the BXU supports cache, I/O prefetch and IAC message functions. The BXU can act as either a master or slave on the L-Bus and requests can flow in either direction between the AP-Bus and the L-Bus. The assumption is, however, that most traffic will flow from the L-Bus out onto the AP-Bus. In a processor-only module, there is no need for the BXU to participate in arbitration for the L-Bus, since it will operate only as a slave.

In Memory mode, the BXU always operates as a master on the L-Bus and no requests are ever accepted from the L-Bus. All requests flow from the AP-Bus into the module. In this mode, the BXU supports memory functions and signaling, but does not provide caching or I/O prefetch.

Read-Modify-Write Transactions

Read-Modify-Write (RMW) operations are provided to give BXUs the ability to read and modify a location as a single indivisible action. A RMW-Read operation initiates the indivisible action by asserting the LOCK signal on the L-bus. A RMW-Write operation is used to terminate the action.

When an RMW-Read transaction occurs, the block of memory addressed is marked by the BXU controlling that portion of memory as locked (the lock covers a fixed address space based on address bits 4 and 6). Once locked, any other RMW-Reads to this block will be rejected, but the block remains available for other types of memory operations.

When an RMW-Read is issued, the BXU controlling the affected memory will either respond with data in a normal Read Reply (and set the appropriate lock), or it will respond with a Reissue Reply indicating that the requested block is already locked. If refused, the requesting BXU will wait a short interval and then put the RMW-Read request back into the arbitration process and try again.

RMW-Writes are equivalent to Write Word(s) except that it resets the lock for that memory location. The only valid reply packet is the Ack (Write Reply).

Interagent Communications (IAC) Support

Bus Extension Units and 80960MC processors communicate by sending Interagent Communication (IAC) messages, which are a set of memory-mapped addresses recognized by all BXUs. These messages are used for such system functions as initialization, cache flushing, access to error logs and interrupts. The upper 16 Mbytes of the 80960MC's 4 Gigabyte address range are reserved for IAC communications.

IAC requests fall into two major groups: messages and register requests. Messages are sent between processors to cause a processor to perform a specific action (e.g., start, stop, flush cache, etc.) and are held in the IAC message support registers; Table 4 summarizes the function of these four registers. Register requests are used by software to read and write to BXU registers in order to control the system operation or configuration.

An IAC message always originates on an L-Bus and usually from a processor. From the originator, the request flows to the BXU where it may be handled internally or propagated on to the AP-Bus. If the IAC is sent on to the AP-Bus, the final destination of the IAC (another BXU) must reside on that bus. The IAC will not be propagated onto another L-Bus or AP-Bus. IAC messages can be one to four words long.

Although each L-Bus (processor or memory module) may be connected to as many as four AP-Buses, at any point in time only one bus will be designated as the message bus. All IAC messages will flow over that bus. The BXUs on the message bus are responsible for handling the IAC message traffic on behalf of the processors residing on their L-Bus (an L-Bus may support one or two processors).

AP-Bus 0 normally serves as the message bus. If AP-Bus 0 is not functional, then AP-Bus 1 serves as the message bus, completely transparent to the software. Processors are unaware of which bus is actually acting as the message bus.

I/O Prefetch Support

The BXU offers two I/O prefetch channels to provide high bandwidth, low latency access to memory for sequential transfers. Each channel buffers 32 bytes of data in two 16-byte blocks. As data is requested from the buffers, the BXU automatically prefetches the next data block. The BXU can take

Table 4. IAC Support Registers

Register	Description
Processor 0 Priority	This register holds the priority of the task (process) which Processor 0 on the BXU's L-Bus is currently executing.
Processor 0 Message	This register buffers four words of data from an IAC message for Processor 0.
Processor 1 Priority	This register holds the priority of the task (process) which Processor 1 on the BXU's L-Bus is currently executing.
Processor 1 Message	This register buffers four words of data from an IAC message for Processor 1.

advantage of the three-deep AP-Bus pipeline to quickly fill the buffers if it ever gets behind because of momentary surges in AP-Bus traffic. In this way, the prefetch logic acts to provide stable, bounded response times, even in large multiprocessor configurations.

Because the normal operation of the BXU hides the latency of write requests by replying immediately on the L-Bus, the prefetch unit operates only for read requests. On a read request from the L-Bus, the prefetch logic returns the amount of data requested. Any processor or intelligent device used with the BXU must guarantee that it will split all memory requests that cross 16-byte boundaries into two requests.

Cache Support

The main function of a cache is to provide local high speed storage for frequently accessed memory locations. Storing the information locally, the cache intercepts memory references and handles them directly without transferring the request to the AP-Bus. This action results in lower traffic on the AP-Bus and decreased latency on the L-Bus, leading to improved performance for a processor on the L-Bus. It also increases potential system performance in a multiprocessor system by reducing each processor's demand for AP-Bus bandwidth, thereby allowing more processors in a system.

The BXU provides cache directory, coherency logic, and control signals, while external SRAM is used for data storage. A CACHE signal output from the 80960MC processor indicates to the BXU whether a request is cacheable. The operation of the BXU cache is not dependent on the size of the data transfer and therefore can support partial writes. Both data and instructions can be contained within the local cache.

The BXU supports a two-way, set associative cache with 64 sets. The (read address) tag field is 20 bits long and consists of LAD lines 31–12. There are eight bits that indicate if a line is valid (a line is 16 bytes). The control bits in the cache control registers can be used to mask some of these bits to change cache configurations. All entries in the directory can be invalidated by sending an INVALIDATE CACHE Command to each BXU in the module. Figure 4 shows one example of a BXU cache directory and its relation to L-Bus addresses.

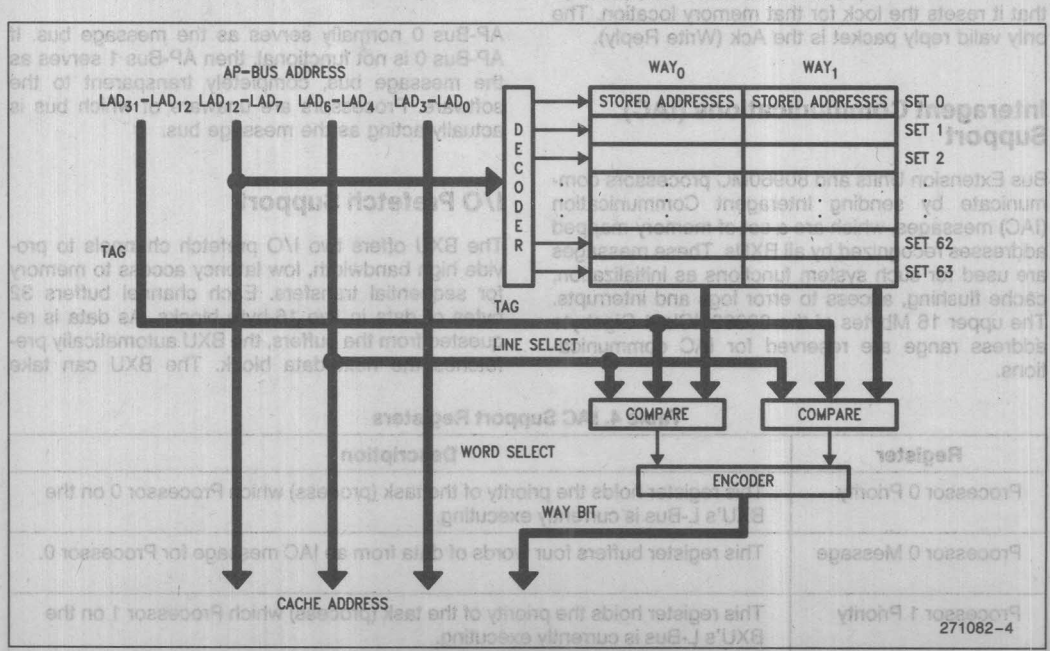


Figure 4. Example of a Cache Directory Array

A single BXU supports 16 Kbytes of cache. When a processor module uses multiple BXUs (and therefore multiple buses), the BXUs cooperate to provide a larger directory and addressing for a larger cache. The best way to view this larger directory is to think of it as having an increased number of sets. Thus a cache managed by two BXUs will have a directory consisting of 128 sets instead of 64. The maximum size cache is 64 Kbytes (four BXUs supporting four AP-Buses per processor module).

The cache is managed using a write-through policy that guarantees that the shared system memory will always have the most recent copy of all data; BXU caches never contain the only copy of revised data. Any time a processor updates a cache entry, it always causes a write request on the AP-Bus, so that there are never any hidden updates. In addition, all BXUs monitor AP-Bus traffic to detect if an update is being made to a location which they are storing in their own cache. If so, that line in the cache directory is marked invalid. This procedure guarantees that a BXU cache will always return correct data even when a system uses multiple caches, when multiple processors treat a single data item differently (some caching, some not), or when two processors are used on a single L-Bus.

An example of an SRAM control design using a single BXU is shown in Figure 5. The BXU supplies six memory control signals to interface the directory and control logic with an external cache composed of static RAM: Cache Read ($\overline{CR}$), Cache Write ($\overline{CW}$), Way0 ($\overline{WY0}$), Way1 ($\overline{WY1}$), Word0 ($\overline{WD0}$), and Word1 ($\overline{WD1}$). SRAM control also requires use of the L-Bus byte enable ($\overline{BE3}$–$\overline{BE0}$) signals and certain address lines. To simplify latching the byte enable signals, the BXU asserts $\overline{READY}$ on all address and recovery cycles as well as when it is transferring data.

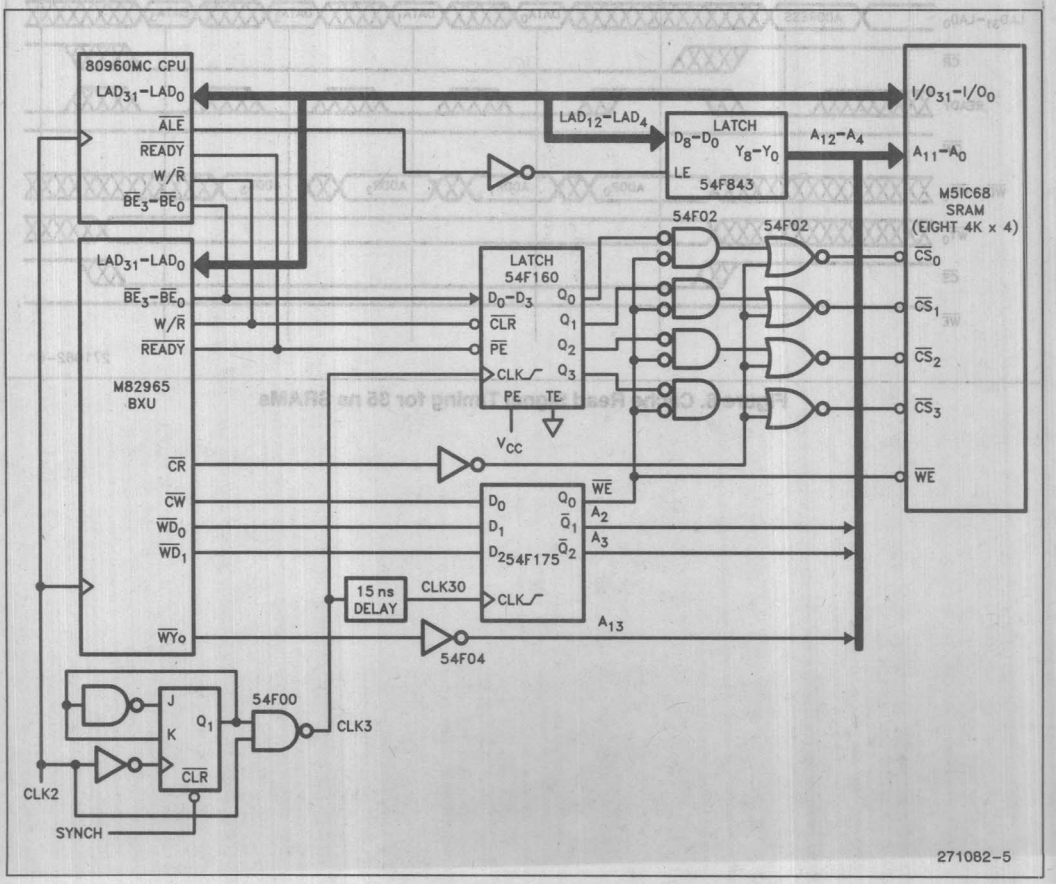


Figure 5. Sample Cache SRAM Control Design Using a BXU

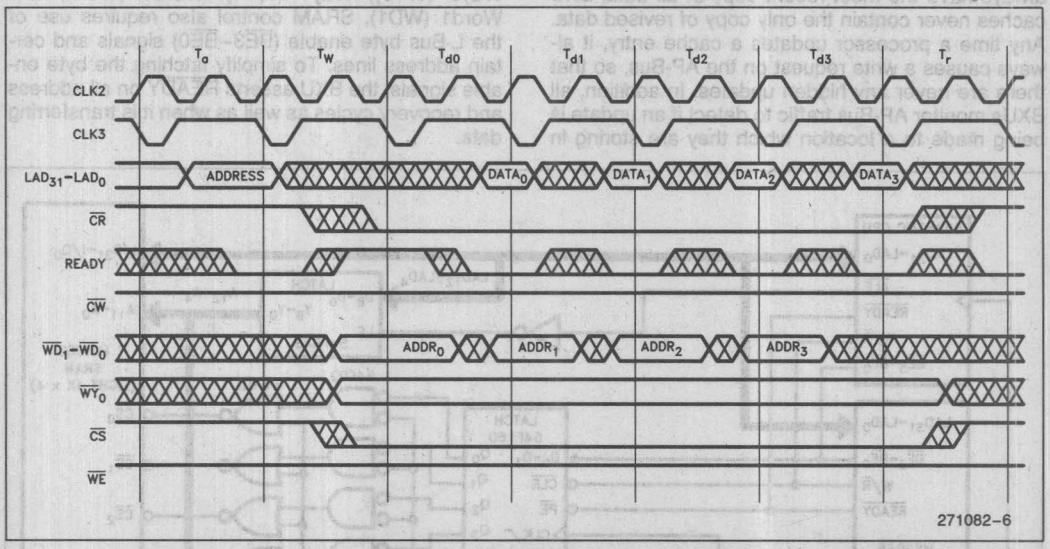


Figure 6. Cache Read Signal Timing for 35 ns SRAMs

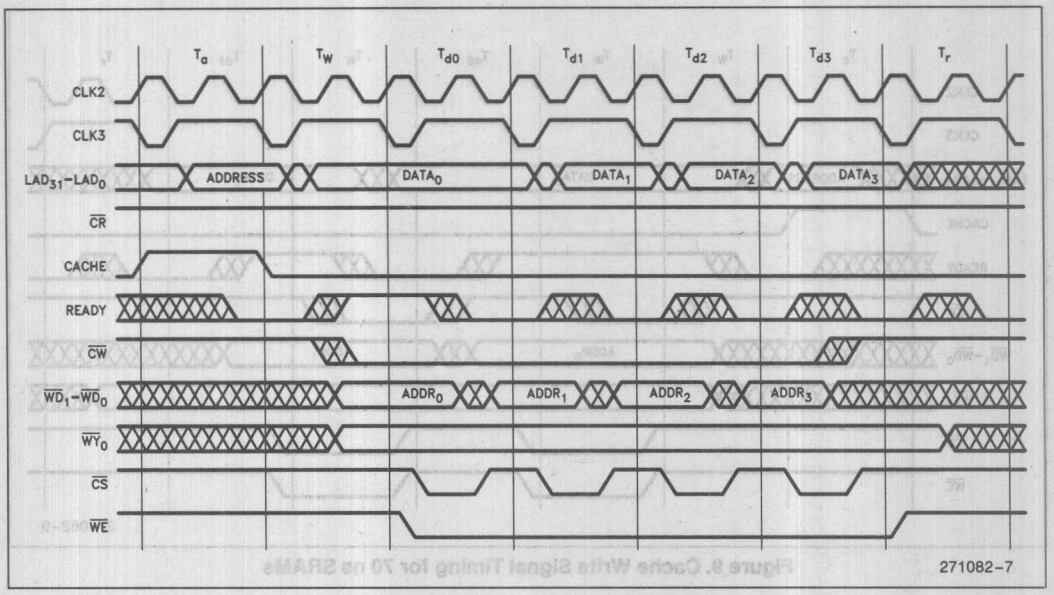


Figure 7. Cache Write Signal Timing for 35 ns SRAMs

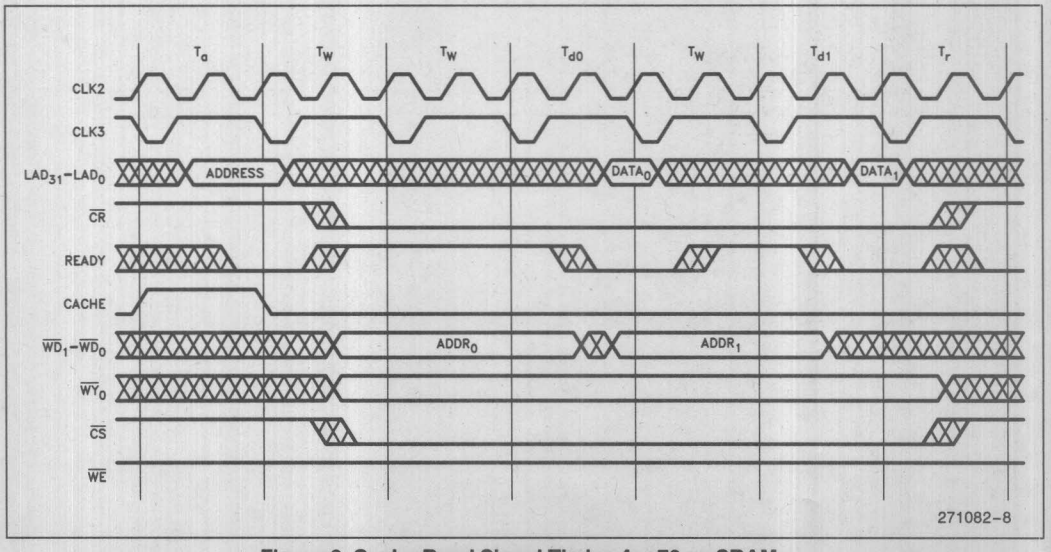


Figure 8. Cache Read Signal Timing for 70 ns SRAMs

5

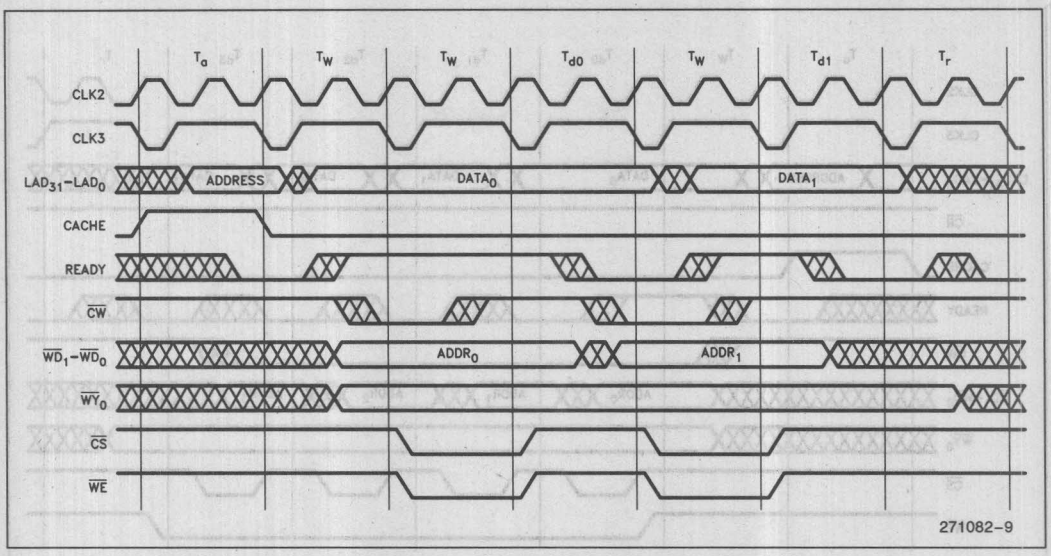


Figure 9. Cache Write Signal Timing for 70 ns SRAMs

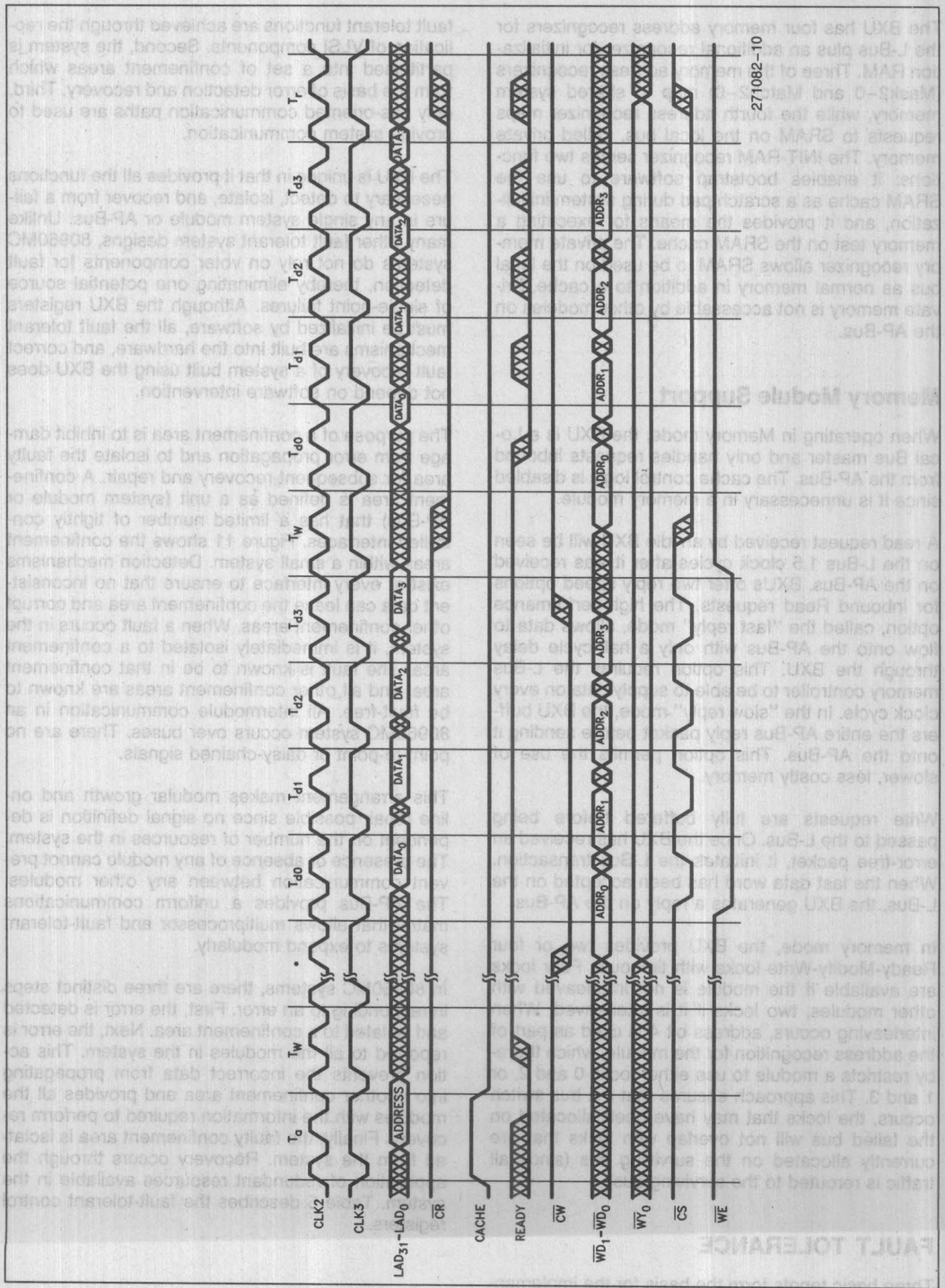


Figure 10. Cache Signal Timing for a 4-Word Read with a Cache Fill for 35 ns SRAMs

The BXU has four memory address recognizers for the L-Bus plus an additional recognizer for initialization RAM. Three of the memory address recognizers (Mask2–0 and Match2–0) map to shared system memory, while the fourth address recognizer maps requests to SRAM on the local bus, called private memory. The INIT-RAM recognizer serves two functions: it enables bootstrap software to use the SRAM cache as a scratch pad during system initialization, and it provides the means for executing a memory test on the SRAM cache. The private memory recognizer allows SRAM to be used on the local bus as normal memory in addition to a cache. Private memory is not accessable by other modules on the AP-Bus.

Memory Module Support

When operating in Memory mode, the BXU is a Local Bus master and only handles requests inbound from the AP-Bus. The cache control logic is disabled since it is unnecessary in a memory module.

A read request received by an idle BXU will be seen on the L-Bus 1.5 clock cycles after it was received on the AP-Bus. BXUs offer two reply speed options for inbound Read requests. The high-performance option, called the "fast reply" mode, allows data to flow onto the AP-Bus with only a half-cycle delay through the BXU. This option requires the L-Bus memory controller to be able to supply data on every clock cycle. In the "slow reply" mode, the BXU buffers the entire AP-Bus reply packet before sending it onto the AP-Bus. This option permits the use of slower, less costly memory.

Write requests are fully buffered before being passed to the L-Bus. Once the BXU has received an error-free packet, it initiates the L-Bus transaction. When the last data word has been accepted on the L-Bus, the BXU generates a reply on the AP-Bus.

In memory mode, the BXU provides two or four Ready-Modify-Write locks with timeouts. Four locks are available if the module is not interleaved with other modules, two locks if it is interleaved. When interleaving occurs, address bit 4 is used as part of the address recognition for the module, which thereby restricts a module to use either locks 0 and 2, or 1 and 3. This approach ensures that if a bus switch occurs, the locks that may have been allocated on the failed bus will not overlap with locks that are currently allocated on the surviving bus (since all traffic is rerouted to the surviving bus).

FAULT TOLERANCE

Three basic tenets form the basis for the implementation of 80960MC fault tolerant systems. First, fault tolerant functions are achieved through the replication of VLSI components. Second, the system is partitioned into a set of confinement areas which form the basis of error detection and recovery. Third, only bus-oriented communication paths are used to provide system communication.

The BXU is unique in that it provides all the functions necessary to detect, isolate, and recover from a failure in any single system module or AP-Bus. Unlike many other fault tolerant system designs, 80960MC systems do not rely on voter components for fault detection, thereby eliminating one potential source of single-point failures. Although the BXU registers must be initialized by software, all the fault tolerant mechanisms are built into the hardware, and correct fault recovery of a system built using the BXU does not depend on software intervention.

The purpose of a confinement area is to inhibit damage from error propagation and to isolate the faulty area for subsequent recovery and repair. A confinement area is defined as a unit (system module or AP-Bus) that has a limited number of tightly controlled interfaces. Figure 11 shows the confinement areas within a small system. Detection mechanisms exist at every interface to ensure that no inconsistent data can leave the confinement area and corrupt other confinement areas. When a fault occurs in the system, it is immediately isolated to a confinement area. The fault is known to be in that confinement area, and all other confinement areas are known to be fault-free. All intermodule communication in an 80960MC system occurs over buses. There are no point-to-point or daisy-chained signals.

This arrangement makes modular growth and online repair possible since no signal definition is dependent on the number of resources in the system. The presence or absence of any module cannot prevent communication between any other modules. The AP-Bus provides a uniform communications matrix that allows multiprocessor and fault-tolerant systems to expand modularly.

In 80960MC systems, there are three distinct steps in responding to an error. First, the error is detected and isolated to a confinement area. Next, the error is reported to all the modules in the system. This action prevents the incorrect data from propagating into another confinement area and provides all the modules with the information required to perform recovery. Finally, the faulty confinement area is isolated from the system. Recovery occurs through the application of redundant resources available in the system. Table 5 describes the fault-tolerant control registers.

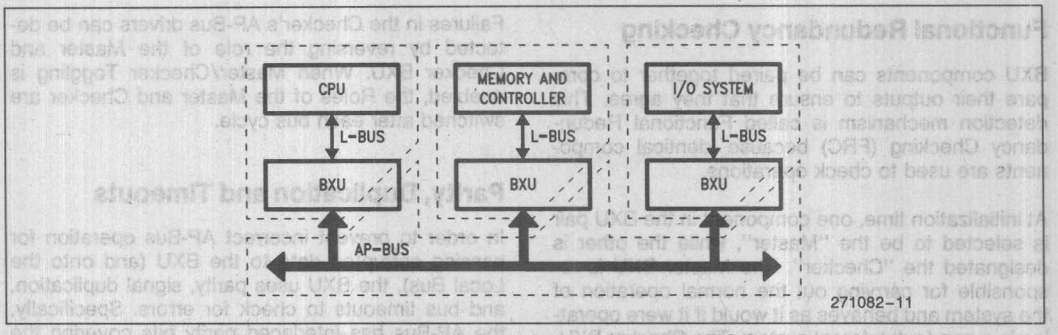


Figure 11. Fault Confinement Areas in an 80960MC System

Table 5. Fault Tolerance Support Registers and Commands

Register	Description
Test Type	The Test Report command instructs the BXU to test the error reporting network. The type of error report generated is determined by the content of this register.
Spouse ID	In a QMR module, this register holds the module ID of the FRC module to which this module is married.
QMR	The contents of this register determine if a module is part of a QMR pair, and if it should function as the primary or shadow in the pair.
Module Error ID	Identifies the BXU as part of a specific module confinement area.
Bus Error ID	Determines the Bus ID contents in an error report.
Error Log	Records the type of the most recent error report received and the number of errors that have occurred since the last Terminate Permanant Error Window command.
Error Record	Holds the contents of the previous error report.
FT2	Holds additional fault-tolerant control parameters.
Test Report Command	The Test Report command instructs the BXU to test the error reporting network. The type of error report generated is determined by the contents of the Test Type Register.
Primary Catastrophe Command	A write to this register causes a Primary Catastrophe error report, usually indicating a primary module power failure.
Shadow Catastrophe Command	A write to this register causes a Shadow Catastrophe error report, usually indicating a shadow module power failure.
Terminate Permanent Error Window Command	A write to this register closes the permanent error window, so that a reoccurance of a previous error is not recorded as permanent.
Attach Bus Command	A write to this register causes the identified bus to be attached to the system and become active.
Detach Bus Command	A write to this register causes the identified bus to be detached from the system and become inactive.
Sync Refresh Command	A write to this register causes BXUs in memory mode to assert their ForceRef pin and enables AP-Bus address matching.

Functional Redundancy Checking

BXU components can be paired together to compare their outputs to ensure that they agree. This detection mechanism is called Functional Redundancy Checking (FRC) because identical components are used to check operations.

At initialization time, one component in the BXU pair is selected to be the "Master", while the other is designated the "Checker". The Master BXU is responsible for carrying out the normal operation of the system and behaves as it would if it were operating in a non-fault tolerant system. The Checker BXU, in contrast, disables its AP-Bus outputs and instead monitors the AP-Bus pins of the Master (see Figure 12). The Checker BXU is responsible for duplicating the operation of the Master and using its internal comparison circuitry to detect any inconsistency between its result and the output of the Master.

The Master and Checker BXUs run in lock step, comparing operations cycle-by-cycle. If at any point the Master or Checker disagree, an FRC error will be signaled and an error reporting cycle will begin.

When using the FRC mechanism, the BXU pins comprising the electrical connection to the AP-Bus must be connected together. A BXU provides FRC coverage on the AD, SPEC, BOUT and MODCHK pins.

Failures in the Checker's AP-Bus drivers can be detected by reversing the role of the Master and Checker BXU. When Master/Checker Toggling is enabled, the Roles of the Master and Checker are switched after each bus cycle.

Parity, Duplication and Timeouts

In order to prevent incorrect AP-Bus operation for passing corrupted data to the BXU (and onto the Local Bus), the BXU uses parity, signal duplication, and bus timeouts to check for errors. Specifically, the AP-Bus has interlaced parity bits covering the AD and SPEC signals, signal duplication is used on both arbitration and RPYDEF, and a bus timer is set to monitor the bus for non-response to a request.

The BXU calculates two separate parity bits across alternate AD and SPEC signals, which are indicated by the CHK0 and CHK1 pins. CHK0 is even parity across the even AD and SPEC pins, and CHK1 is even parity across the odd pins. Since the arbitration and RPYDEF lines are driven independently by multiple bus agents (BXUs), parity cannot be used for error detection, rather the detection of errors is done by duplicating each set of lines, one set for Masters, the other set for Checkers. Consequently, each BXU connects to only one arbitration network. If there is a disagreement between the two sets of signals on

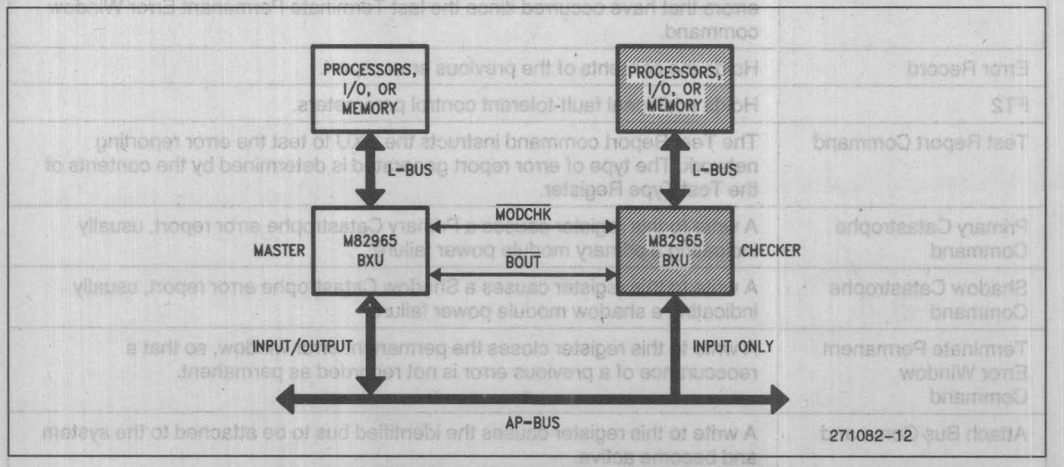


Figure 12. Functional Redundancy Checking (FRC)

the AP-Bus, it will be detected through an FRC disagreement. The BXU uses a timer to determine if no response has been received and too long a period has elapsed since the bus request was made. During normal operation the timer is active whenever the bus pipeline is not empty. The timer is reset on every bus reply or deferral. If the BXU was the source of the requests and a timeout occurs, it signals a Bad Access Reply on the AP-Bus. The timer is nominally 64 clocks.

Error Reporting

The error reporting network is the backbone of fault isolation and recovery. When an error is detected, the BXU detecting the error reports its type and location to all other nodes in the system. The error reporting network is designed so that, independent of an error in the system, each node not only receives an error report, but is guaranteed to receive the same error report. Each BXU in the system uniformly logs each error report, and is able to use this information to proceed independently with the appropriate recovery procedure.

The BXU has two serial Error Reporting Lines associated with each bus interface (BERLs for the AP-Bus and LERLs for the Local Bus). An indentical serial error report is sent over each pair of lines associated with each bus.

An AP-Bus error reporting cycle consists of five phases: Reporting, Partner Communications, Transient Waiting Period, Retry, and the Permanent Error Window (see Figure 13). The reporting phase lasts 256 cycles from the beginning of the first report received on the BXU's error reporting lines. The BXU becomes quiescent as soon as it detects the start bit of an error report and remains quiescent through the Transient Waiting Period.

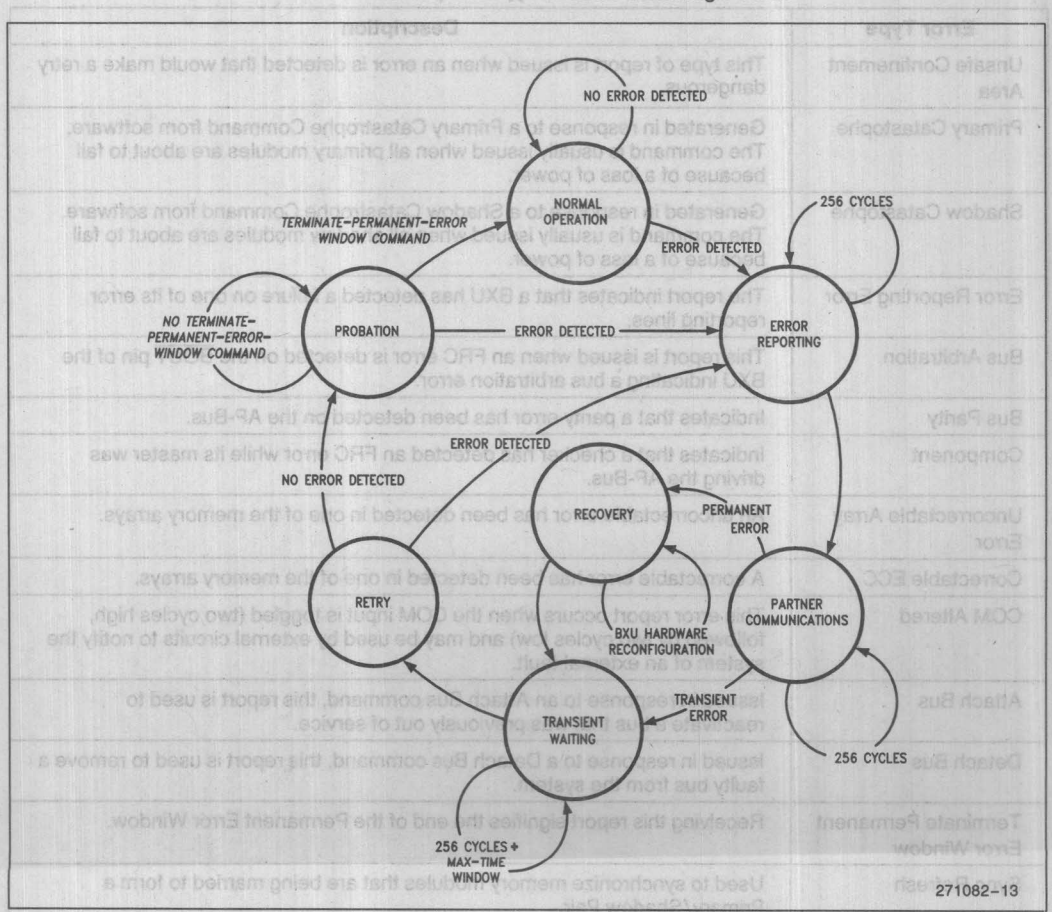


Figure 13. Error Reporting Cycle

During partner communications, BXUs communicate with each other via their POPQUE lines to determine whether to retry accesses in the case that one of the AP-Buses is removed from the system. Partner ordering lasts 256 cycles.

Transient waiting enables the system to sustain disturbances from mechanical vibrations and brief electrical transients without needing to permanently reconfigure the system. The BXUs simply wait a predetermined time for the transient to subside. The duration of the Transient Waiting Period is adjustable and can be set by software (16 μs to 500 ms at 16 MHz). During this period, the BXU completes its internal recovery mechanisms (if the error is permanent). Since the transient waiting mechanism on the buses depends on all buses moving to the retry state at the same time, all BXUs must have identical values for the Transient Waiting Period.

During the RETRY phase, all accesses that were pending at the time that the error report was received will be retried. At the same time as RETRY begins, the BXU enters the Permanent Error Window. During this interval, the BXU watches for the error to reoccur.

Each BXU has two registers that are used for logging error reports. The ERROR LOG register contains the current error report and the ERROR RECORD register contains the previous error report. When a error report is received, the contents of the ERROR LOG register are copied into the ERROR RECORD register. Both registers are accessible by software and are the primary means by which the software routines responsible for system management communicate with the hardware fault handling mechanisms. Table 6 lists the types of errors that can be reported.

Table 6. Error Types Reported

Error Type	Description
Unsafe Confinement Area	This type of report is issued when an error is detected that would make a retry dangerous.
Primary Catastophe	Generated in response to a Primary Catastrophe Command from software. The command is usually issued when all primary modules are about to fail because of a loss of power.
Shadow Catastophe	Generated in response to a Shadow Catastrophe Command from software. The command is usually issued when all shadow modules are about to fail because of a loss of power.
Error Reporting Error	The report indicates that a BXU has detected a failure on one of its error reporting lines.
Bus Arbitration	This report is issued when an FRC error is detected on the $\overline{\text{BOUT}}$ pin of the BXU indicating a bus arbitration error.
Bus Parity	Indicates that a parity error has been detected on the AP-Bus.
Component	Indicates that a checker has detected an FRC error while its master was driving the AP-Bus.
Uncorrectable Array Error	An uncorrectable error has been detected in one of the memory arrays.
Correctable ECC	A correctable error has been detected in one of the memory arrays.
COM Altered	This error report occurs when the COM input is toggled (two cycles high, followed by two cycles low) and may be used by external circuits to notify the system of an external fault.
Attach Bus	Issued in response to an Attach Bus command, this report is used to reactivate a bus that was previously out of service.
Detach Bus	Issued in response to a Detach Bus command, this report is used to remove a faulty bus from the system.
Terminate Permanent Error Window	Receiving this report signifies the end of the Permanent Error Window.
Sync Refresh	Used to synchronize memory modules that are being married to form a Primary/Shadow Pair.

The BXU's hardware compares the contents of the two error reporting registers to determine if a bus retry has resulted in a repeat of the previous error (which therefore must be considered a permanent error). Software can clear the two registers by sending a Terminate Permanent Error Window command. The registers allow software to monitor the health of the system and to respond appropriately in case of hardware problems. The availability of this information simplifies diagnostic routines.

The ERROR LOG register is handled independently by hardware and software; hardware always responds immediately to an error report so that it is never lost by failure of software to respond. During normal system operation, software should never write to this register, since it is both read and written by hardware. The ERROR LOG register is cleared on a cold start, but its contents are retained across a warm start.

RECOVERY MECHANISMS

Module Shadowing

Automatic recovery from permanent single-point failures in a module is accomplished through module shadowing, or what is more formally called Quad Modular Redundancy (QMR). Using this technique, two FRC pairs (master/checker) of the same type are logically linked to form a primary/shadow pair (see Figure 14). The marriage of the two modules is performed by software which sets the logical ID of the two modules equal and restarts them in lock step (or synchronous operation). There is no direct electrical connection between a primary/shadow pair. They are usually on separate boards so that either can be removed in the case of a failure in that module.

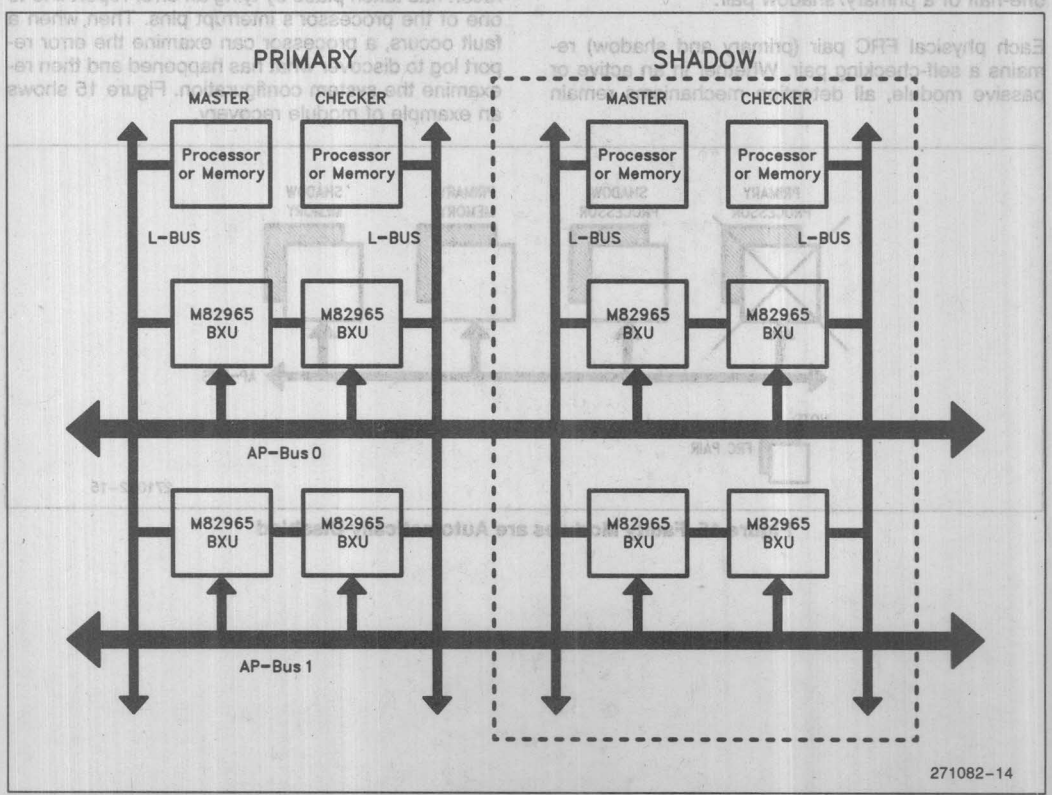


Figure 14. In Quad Modular Redundancy (QMR), Self-Checking Modules are Paired

The primary/shadow pair operate in lock step so that there is always a complete and current backup for an FRC pair. At any point in time, one FRC pair will be active (i.e., sending its output to the AP-Bus) while the other will be passive (i.e., its outputs will be disabled). Initially, the primary FRC pair is active and is responsible for issuing requests or replies to the AP-Bus. Data leaves only by means of the active FRC pair.

As an option, the roles of active and passive modules are switched after every second bus cycle. (In contrast, master/checker pairs are toggled every cycle). This ping-pong action exercises all of the logic in both primary and shadow modules. Any latent failure that exists in the AP-Bus drivers will be detected immediately. All of the logic to perform this lock step operation is contained in the BXU and neither the processors nor any discrete logic contained in a module is aware that the module is participating as one-half of a primary/shadow pair.

Each physical FRC pair (primary and shadow) remains a self-checking pair. Whether in an active or passive module, all detection mechanisms remain enabled and continuously check the operation of that module. Neither the primary nor the shadow check the operation of the other; FRC is used for fault detection, while module shadowing (Quad Modular Redundancy) is used to ensure immediate recovery.

Automatic Module Recovery

If a permanent error is detected in either a primary or a shadow FRC pair, the faulty pair will immediately be disabled as all BXUs in the pair shutdown. The surviving spouse then separates itself from the faulty FRC pair and operates as an active pair on every bus cycle. At that point, recovery is complete.

Hardware recovery is autonomous and requires no software intervention to complete. The operating system can be informed that a hardware reconfiguration has taken place by tying an error report line to one of the processor's interrupt pins. Then when a fault occurs, a processor can examine the error report log to discover what has happened and then reexamine the system configuration. Figure 15 shows an example of module recovery.

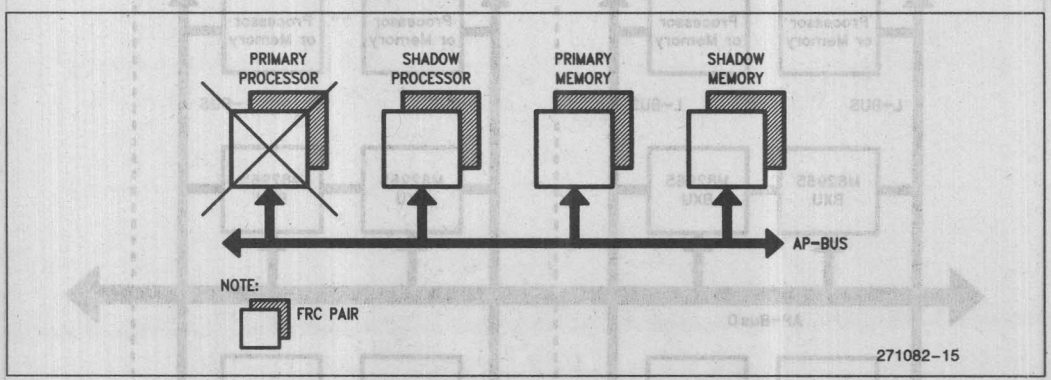


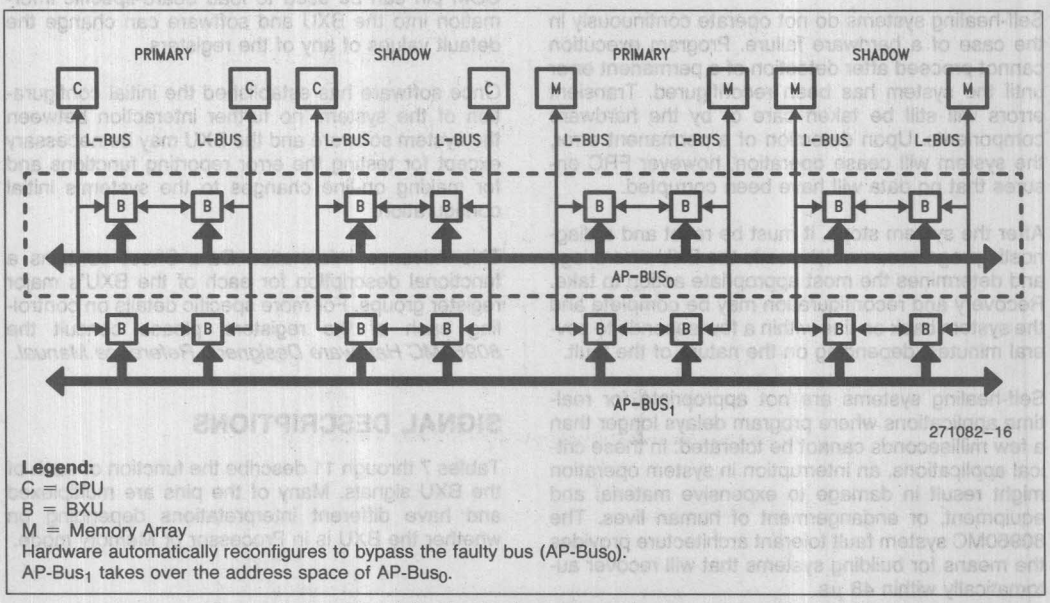
Figure 15. Faulty Modules are Automatically Disabled

Bus Switching

All AP-Buses in an 80960MC system are physically identical, but when a system is operational each bus handles a unique address range. The BXU has been designed so that it is possible to pair together two AP-Busses and have them act as redundant or alternate resources for each other. AP-Bus 0 is paired with AP-Bus 1 and AP-Bus 2 is paired with AP-Bus 3. In order for an FRC pair to have an additional bus, it must also have another pair of Master/Checker BXUs. Normally the memory addresses will be interleaved between the two (or four) buses, but this isn't necessary for bus switching.

Since the AP-Bus does not hold state information (as do processors and memory), all buses in the system may be used during normal operation. There is no degradation of throughput to achieve bus redundancy. Each bus is fully operational.

When a permanent error has been detected on an AP-Bus, all BXUs on the faulty bus disable themselves. L-Bus requests for the failed bus will be ignored by the disabled BXUs and picked up instead by the BXUs attached to the backup bus. If a BXU has a cache, the BXU invalidates its cache directory since the directory must be reorganized to match the new (and larger) address space, including a new interleaving factor. Figure 16 shows an example of bus switching.



Legend:
C = CPU
B = BXU
M = Memory Array
Hardware automatically reconfigures to bypass the faulty bus (AP-Bus_0).
AP-Bus_1 takes over the address space of AP-Bus_0.

Figure 16. If a Bus Fails, Its Backup Bus Takes Over Immediately

5

Self-Healing Systems

In some applications it is important to guarantee the integrity of the data, but momentary interruptions in processing can occur without seriously affecting operations or jeopardizing human lives. For these applications, a cost effective approach may be to use self-healing systems.

Self-healing systems use Functional Redundancy Checking to ensure that all errors are detected and that faults are confined within a module. Fault recovery is not automatic; recovery and reconfiguration is done by software following error detection. Self-healing systems are less costly than fully fault-tolerant systems because fewer components are necessary.

Self-healing systems do not operate continuously in the case of a hardware failure. Program execution cannot proceed after detection of a permanent error until the system has been reconfigured. Transient errors will still be taken care of by the hardware components. Upon detection of a permanent error, the system will cease operation, however FRC ensures that no data will have been corrupted.

After the system stops, it must be reset and a diagnostic program run which reads the BXU errors logs and determines the most appropriate action to take. Recovery and reconfiguration may be complete and the system back on-line within a few seconds to several minutes, depending on the nature of the fault.

Self-healing systems are not appropriate for real-time applications where program delays longer than a few milliseconds cannot be tolerated. In these critical applications, an interruption in system operation might result in damage to expensive material and equipment, or endangerment of human lives. The 80960MC system fault tolerant architecture provides the means for building systems that will recover automatically within 48 μs.

BXU Registers

Initialization and control of the BXU is done by reading and writing the BXU's internal registers. The registers are mapped to the upper 16 Mbytes of the 80960MC processor's physical address space.

Initialization of a system using BXUs occurs in three stages. In the first stage which immediately follows RESET, all registers (except for the registers containing error report information) are loaded with 0 or with values sampled off a set of pins.

During this stage the BXU's System Bus ID and mode of operation are established. In the second stage, software assigns logical, physical, and arbitration IDs to each BXU. Then in the third stage, the COM pin can be used to load board-specific information into the BXU and software can change the default values of any of the registers.

Once software has established the initial configuration of the system, no further interaction between the system software and the BXU may be necessary except for testing the error reporting functions and for making on-line changes to the system's initial configuration.

This Advance Information Data Sheet contains a functional description for each of the BXU's major register groups. For more specific details on controlling each of the registers, please consult the *80960MC Hardware Designer's Reference Manual*.

SIGNAL DESCRIPTIONS

Tables 7 through 11 describe the function of each of the BXU signals. Many of the pins are multiplexed and have different interpretations depending on whether the BXU is in Processor or Memory mode.

Table 7. M82965 BXU L-Bus Signals

Symbol	Type	Name and Function
LAD_{31} $-LAD_0$	I/O T.S.	**LOCAL ADDRESS/DATA BUS:** Carries 32-bit physical addresses and data to and from a processor or memory. During an address (T_a) cycle, bits 2–31 contain a physical word addres (bits 0–1 indicate SIZE; see below). During a data (T_d) cycle, bits 0–31 contain read or write data. The LAD lines are active HIGH and float to a three-state OFF when the bus is not acquired. **SIZE:** Which is comprised of bits 0–1 of the LAD bus during a T_a cycle, specifies the size of a transfer in words. LAD_1 LAD_0 0 0 1 Word 0 1 2 Words 1 0 3 Words 1 1 4 Words
$\overline{ALE}$	O T.S.	**ADDRESS-LATCH ENABLE:** Indicates the transfer of a physical address. $\overline{ALE}$ is asserted during a T_a cycle,and deasserted during T_d cycles and the second half of T_a cycles. It is active LOW and floats to a three-state OFF when the L-Bus is not acquired.
$\overline{ADS}$	I/O O.D.	**ADDRESS STATUS:** Is used to detect address cycles and additional data cycles.
CACHE	I	**CACHEABLE:** During a T_a cycle, specifies whether data is cacheable. **When operating in the MEMORY mode this pin should be tied to ground through a 10 kΩ resistor.**
W/$\overline{R}$	I/O O.D.	**WRITE/READ:** specifies, during a T_a cycle, whether the operation is a write or read. It is latched on-chip and remains valid during T_d cycles.
$\overline{CW}/\overline{DEN}$	O O.D.	**CACHE WRITE:** (Defined only when the BXU is in PROCESSOR mode). This signal indicates that the cache SRAM should be written with data from the L-Bus and is used to generate the chip select, and write enable signals required by the SRAM. The signal is open drain so it can be shared among multiple BXUs controlling a single set of SRAMs. **DATA ENABLE:** (Defined only when the BXU is in MEMORY mode). Is asserted during T_D cycles and indicates transfer of data on the local AD bus lines.
$\overline{CR}$/ DT/$\overline{R}$	O O.D.	**CACHE READ:** (Defined only when the BXU is in PROCESSOR mode). This signal indicates that the cache SRAM should drive data onto the L-Bus in response to a read request and is used to generate the chip select and output enable signals required by the SRAM. This signal is open drain so it can be shared among multiple BXUs controlling a single cache. **DATA TRANSMIT/RECEIVE:** (Defined only when the BXU is in MEMORY mode). Indicates the direction of data transfer. It is low during T_a and T_d cycles for a read or interrupt acknowledgement; it is high during T_a and T_d cycles for a write. DT/$\overline{R}$ never changes state when $\overline{DEN}$ is asserted.
$\overline{LOCK}$	I	**BUS LOCK:** Is used by the BXU to distinguish between normal reads and RMW-reads, normal writes and RMW-writes. An 80960MC processor asserts $\overline{LOCK}$ at the beginning of an RMW cycle, and the BXU recognizes it as an RMW-read. If the read operation is accepted by the module serving memory, the processor drops $\overline{LOCK}$, and executes an RMW-write. $\overline{LOCK}$ is also held asserted during an interrupt-acknowledge transaction.
$\overline{READY}$	I/O O.D	**READY:** Indicates that data on LAD lines can be sampled or removed. If $\overline{READY}$ is not asserted during a T_d cycle, the T_d cycle is extended to the next cycle, and $\overline{ADS}$ is not asserted in the next cycle. $\overline{READY}$ is driven on T_a, T_r and T_i cycles.

NOTES:
I/O = Input/Output, I = Input, O = Output, O.D. = Open Drain, T.S. = three-state

5

Table 7. M82965 BXU L-Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{BE_3}$–$\overline{BE_0}$	I/O O.D.	**BYTE ENABLES:** Specify which data bytes on the local bus will take part in the next bus cycle. $\overline{BE_3}$ corresponds to LAD_{24}–LAD_{31} and $\overline{BE_0}$ corresponds to LAD_0–LAD_7.
HOLD/ HOLDAR	I	**HOLD:** Indicates that a master I/O peripheral requests control of the bus. When the BXU receives HOLD and grants the peripheral control of the bus, it floats the bus lines and then asserts HLDA and enters the T_h state. When HOLD is deasserted, the BXU will deassert HLDA and go to either the T_i or T_a state.
		HOLD ACKNOWLEDGE REQUEST: Is an input to the secondary bus master that the primary bus master has relinquished control of the bus.
HLDA/ HOLDR	O	**HOLD ACKNOWLEDGE:** Relinquishes control of the bus to a master I/O peripheral.
		HOLD REQUST: Is used by a Secondary Bus Master to request use of the bus from the Primary Bus Master.

Table 8. M82965 BXU L-Bus Module Support Signals

Symbol	Type	Name and Function
$\overline{BADAC}$	O O.D.	**BAD ACCESS:** If asserted in the cycle following the one in which the last $\overline{READY}$ of a transaction is asserted as a result of a bad access, it indicates that the transaction has exceeded the AP-Bus time-out period.
$\overline{IAC_0}/\overline{ERR}$	I/O O.D.	**INTERAGENT COMMUNICATION: PROCESSOR 0:** (Defined only when the BXU is in PROCESSOR mode). Is an open-drain output that indicates that there is a pending IAC message for Processor 0 on the BXU's local bus. **EXTERNAL ERROR:** (Defined only when the BXU is in MEMORY mode). Is an input that indicates that an error has been detected in external logic (e.g., a failure in a discrete memory controller).
$\overline{IAC_1}/\overline{FRF}$	O O.D.	**INTERAGENT COMMUNICATION: PROCESSOR 1:** (Defined only when the BXU is in PROCESSOR mode). Is an open-drain output that indicates that there is a pending IAC message for Processor 1 on the BXU's local bus. **FORCE REFRESH:** (Defined only when the BXU is in memory mode). Is an open-drain output that tells the external memory controller to immediately execute a refresh operation.
$\overline{PFETCH}$	I	**PREFETCH:** Is used in conjunction with the Cache and Write/Read (W/$\overline{R}$) signals to define the type of request being issued (0 = LO, 1 = HI): **PFETCH CACHE W/$\overline{R}$** 0 0 0 Read using Prefetch Channel 0 0 0 1 Start for Prefetch Channel 0 0 1 0 Read using Prefetch Channel 1 0 1 1 Start for Prefetch Channel 1 1 0 0 Noncacheable Read 1 0 1 Noncacheable Write 1 1 0 Cacheable Read 1 1 1 Cacheable Write

NOTES:
I/O = Input/Output, I = Input, O = Output, O.D. = Open Drain

Table 9. M82965 BXU AP-Bus Signals

Symbol	Type	Name and Function
$\overline{AD}_{31}$–$\overline{AD}_0$	I/O O.D.	**SYSTEM ADDRESS/DATA LINES:** Carry 32-bit addresses and data between modules (BXUs) on an AP-Bus. The content of the AD lines is defined by the SPEC encoding during the same bus cycle.
$\overline{SPEC}_5$–$\overline{SPEC}_0$	I/O O.D.	**PACKET SPECIFICATION:** Signals define the packet type and the parameters required for the transaction: **$SPEC_5$: REQUEST:** Is asserted if the packet is a request packet. **$SPEC_4$: MULTICYCLE:** Is asserted if the packet consists of more than one bus cycle. **$SPEC_3$–$SPEC_2$: CYCLE COUNT:** These two bits are used in conjunction with Request and Multicycle signals to specify the length of the packet (in bus cycles) and the data length (in words). **$SPEC_1$–$SPEC_0$: OPERATION/STATUS TYPE:** These two bits identify the specific operation or status conveyed by the packet.
$\overline{CHK}_1$–$\overline{CHK}_0$	I/O O.D.	**CHECK SIGNALS:** Provide interlaced parity for the $\overline{SPEC}$ and $\overline{AD}$ lines.
$\overline{ARB}_3$–$\overline{ARB}_0$	I/O O.D.	**ARBITRATION:** Signals are used by the bus agents (BXUs) to determine which agent has access to the bus next. These signals have a timing that is one-half cycle out of phase with the $\overline{AD}$ lines.
$\overline{RPYDEF}$	I/O O.D.	**REPLY DEFER:** Signal allows an agent to give up its "slot" on the bus temporarily if its access is going to take a long time. This action reorders the pipeline, moving the deferred request to the bottom of the queue, resets the bus time-out counter and permits another agent to use the bus.
$\overline{BERL}_1$–$\overline{BERL}_0$	I/O O.D.	**BUS ERROR REPORT LINES:** Is used to signal errors from bus transactions or from within modules connected to the bus.

NOTES:
I/O = Input/Output, I = Input, O = Output, O.D. = Open Drain

5

Table 10. M82965 BXU AP-Bus (Local Agent) Support Signals

Symbol	Type	Name and Function
CLK2	I	**SYSTEM CLOCK:** Provides the base timing and synchronization for all agents (BXUs) in the system. It is sourced to all agents from a central clock and is twice the frequency of the bus cycle. **NOTE:** The clock skew over the AP-Bus for a typical system should be no greater than 6 ns for correct system operation.
$\overline{BOUT}$	I/O O.D.	**BUS OUTPUT CONTROL:** Is asserted whenever a component is driving the AP-Bus. Functional Redundancy Checks on $\overline{BOUT}$ can be used to detect arbitration failures.
$\overline{MODCHK}$	I/O O.D.	**MODULE CHECK:** Is connected between Master/Checker pairs, allowing a Functional Redundancy Check to be performed on internal states.
$\overline{INITID}$	I	**INITIALIZE ID:** Is connected to one of the 32 $\overline{AD}$ lines and is used in conjunction with the IDENTIFY DEVICE IAC to provide a unique address for each BXU at initialization time.
V_{REF}	I	**VOLTAGE REFERENCE:** Provides a stable voltage reference for the input buffers of components connected to the AP-Bus. External hardware must provide a V_{REF}/W voltage (see Table 14) on the V_{REF} pin during normal operation of the component. The V_{REF} pin is also used to distinguish between a warm start (system memory and the Error Record register retain their state) and a cold start (system memory and BXU registers are cleared).
RESET	I	**RESET:** Forces all agents on the bus to reset and synchronize. The bus cycle begins the first CLK2 period after RESET is deasserted. The RESET signal is the way a BXU is synchronized to the rest of the system.
$\overline{COM}$	I/O O.D.	**COMMUNICATION:** Can be used to load information into a component as part of the initialization sequence or to inform external logic that the component has failed. The BXU will asserted $\overline{COM}$ if it has shut itself off due to a failure in its module. The $\overline{COM}$ signal is not involved in any aspect of AP-Bus operation, but can be used to load board-dependent information into the BXU or to signal the rest of the system that an external error has occurred.

NOTES:
I/O = Input/Output, I = Input, O = Output, O.D. = Open Drain

Table 11. M82965 BXU Module Support Signals

Symbol	Type	Name and Function
$\overline{WY_0}/\overline{COR}$	O O.D.	**WAY_0:** (When the BXU is in processor mode). Indicates which one of the two "ways" in a directory set had a cache hit. The line is intended to drive the SRAM address pins and will remain stable throughout the length of a cache access. **CORRECT:** (When the BXU is in memory mode). Is used by the BXU to tell an external ECC controller to correct the memory data as it flows onto the local bus. If this signal is not asserted, then the memory data may flow directly onto the local bus with only error checking, but no correction.
$\overline{WY_1}$/MEM	O O.D.	**WAY_1:** (Defined only when the BXU is in PROCESSOR mode). Indicates if the access is for the cache or private memory half of the SRAM. The line is intended to drive the SRAM address lines directly and will remain stable throughout the length of a cache access. **MEMORY/REGISTER REQUEST:** (Defined only when the BXU is in MEMORY mode). This signal allows mapping some of the BXU's register space out to the registers in an external controller. If the signal is high, the associated L-Bus request is a memory request; otherwise, the L-Bus request is to an external register on the board.
$\overline{WD_0}/\overline{UNC}$	I/O O.D.	**$WORD_0$:** (Only defined when the BXU is in PROCESSOR mode). Provides the low order bit of the word address for the SRAM. Together with $WORD_1$, the two bits indicate which of the four words within an address line should be addressed. Because SRAM timing is critical, an external latch could be required. The signals change for each word of data transferred. **UNCORRECTABLE ECC:** (Only defined when the BXU is in MEMORY mode). Is an input used by the external ECC logic to signal to the BXU that it has detected an uncorrectable memory error.
$\overline{WD_1}/\overline{ECC}$	I/O O.D.	**$WORD_1$:** (Defined only when the BXU is in PROCESSOR mode). Provides the high order bit of the word address for the SRAM. Together with $WORD_0$, the two bits indicate which of the four words within an address line should be addressed. Because SRAM timing is critical, an external latch will be required. The signals change for each word of data transferred. **ECC ERROR:** (Defined only when the BXU is in MEMORY mode). Is an input used by the external ECC logic to signal to the BXU that it has detected a memory error. The signal will be asserted even though external logic may be correcting the error and providing correct data on the L-Bus. If the BXU is asserting its $\overline{CORRECT}$ signal, the ECC ERROR signal will be ignored. Only the $\overline{UNC}$ pin will be checked for an error indication under these conditions.
$\overline{SSBUSY}$	I/O O.D.	**SUBSYSTEM BUSY:** Connects together all BXUs in a module that are in the same subsystem. When the signal is pulled low (BUSY), the BXUs will accept a request address, but will not continue with the data cycles. This signal is used to ensure that the BXUs always handle RMW-writes, Interagent Communication messages, and retries correctly. An external signal is needed because BXUs can generate AP-Bus requests internally because of the prefetcher, or their internal logic can be tied up handling an IAC request from the AP-Bus.

5

Table 11. M82965 BXU Module Support Signals (Continued)

Symbol	Type	Name and Function
$\overline{POPQUE}$	I/O O.D.	**POP QUEUE:** Is used by the two BXUs acting as bus backups for each other to communicate status on the completion of outstanding L-Bus requests. Usually, this signal is asserted when the oldest write in the queue has completed. During the partner ordering period, a different protocol is used to convey the status of all write requests outstanding.
$\overline{LERL_1}$–$\overline{LERL_0}$	I/O O.D.	**LOCAL ERROR REPORTING LINES:** Are identical to the BERL signals defined for the AP-Bus, but are used on the module side to connect all BXUs on a single L-Bus.

NOTES:
I/O = Input/Output, I = Input, O = Output, O.D. = Open Drain

MECHANICAL DATA

Pin Assignment

The MG82965 BXU (PGA package) pinout as viewed from the top side of the component (pins down) is shown in Figure 17 and from the bottom side (pins up) in Figure 18.

V_{CC} and GND connections must be made to multiple V_{CC} and GND pins. Each V_{CC} and GND pin must be connected to the appropriate voltage or ground and externally strapped close to the package. Preferably, the circuit board should include power and ground planes for power distribution. Table 12 lists the function of each pin.

Many of the signals are multiplexed and several signals have different interpretations depending on whether the BXU is used in Processor or Memory mode.

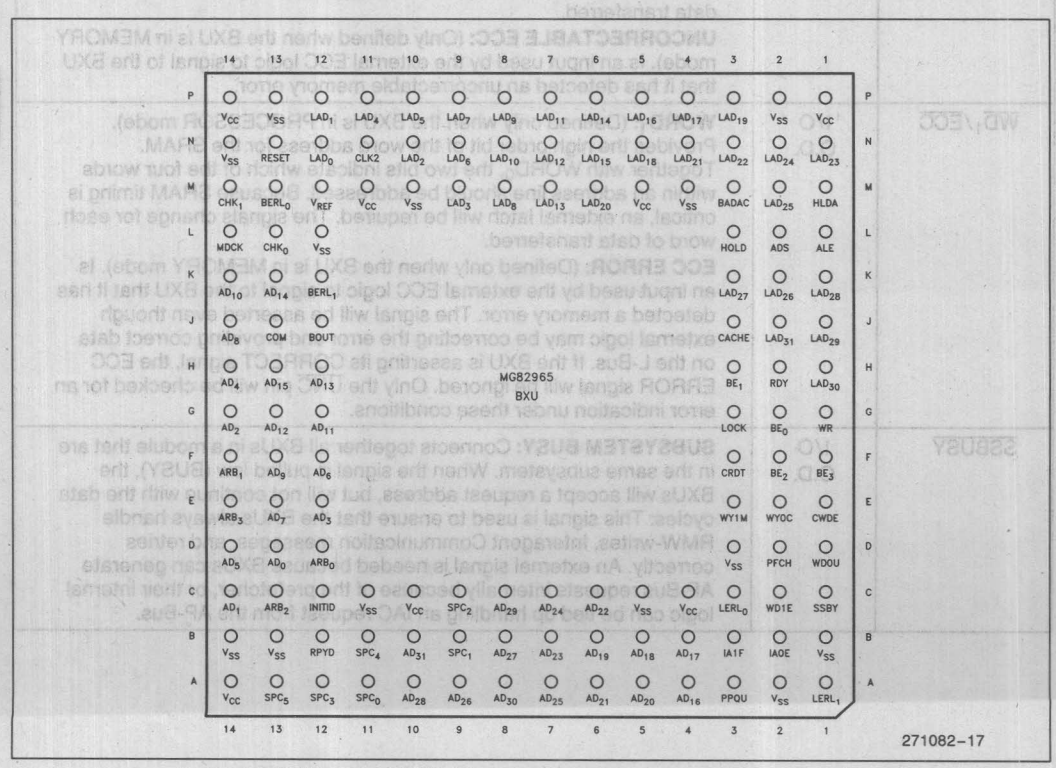


Figure 17. MG82965 BXU Pinout—View from Top Side (Pins Down)

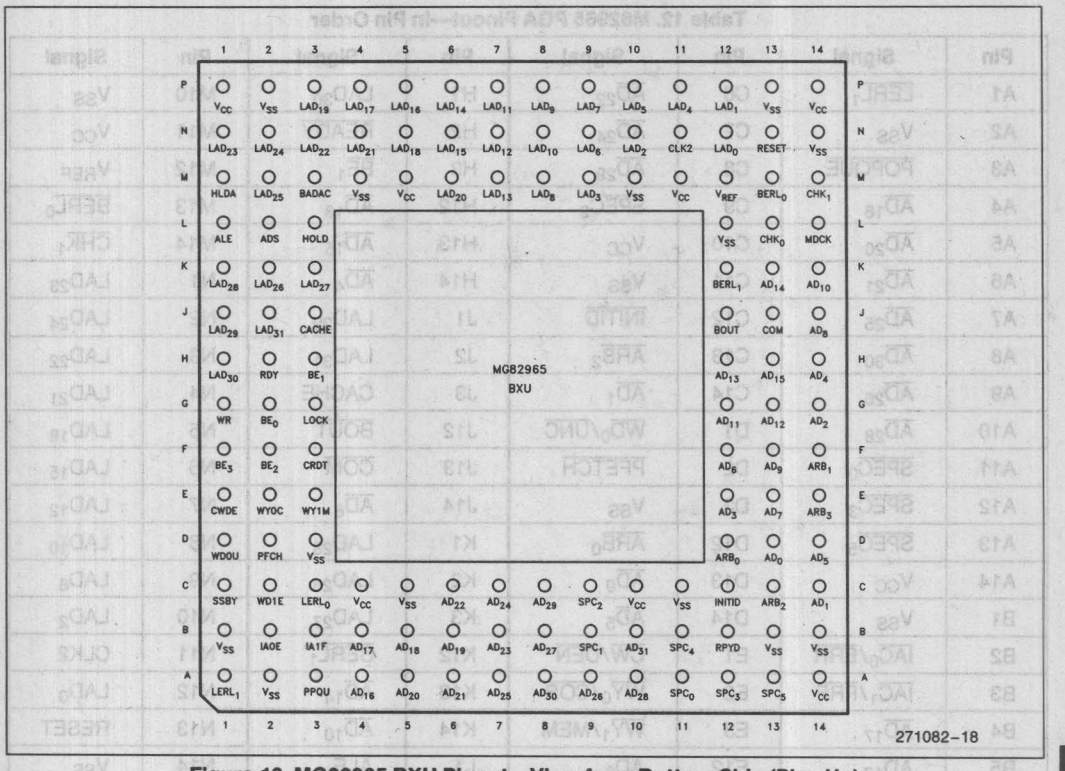


Figure 18. MG82965 BXU Pinout—View from Bottom Side (Pins Up)

5

Table 12. M82965 PGA Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
A1	$\overline{LERL_1}$	C6	$\overline{AD_{22}}$	H1	LAD_{30}	M10	V_{SS}
A2	V_{SS}	C7	$\overline{AD_{24}}$	H2	$\overline{READY}$	M11	V_{CC}
A3	$\overline{POPQUE}$	C8	$\overline{AD_{29}}$	H3	$\overline{BE_1}$	M12	V_{REF}
A4	$\overline{AD_{16}}$	C9	$\overline{SPEC_2}$	H12	$\overline{AD_{13}}$	M13	$\overline{BERL_0}$
A5	$\overline{AD_{20}}$	C10	V_{CC}	H13	$\overline{AD_{15}}$	M14	$\overline{CHK_1}$
A6	$\overline{AD_{21}}$	C11	V_{SS}	H14	$\overline{AD_4}$	N1	LAD_{23}
A7	$\overline{AD_{25}}$	C12	$\overline{INITID}$	J1	LAD_{29}	N2	LAD_{24}
A8	$\overline{AD_{30}}$	C13	$\overline{ARB_2}$	J2	LAD_{31}	N3	LAD_{22}
A9	$\overline{AD_{26}}$	C14	$\overline{AD_1}$	J3	CACHE	N4	LAD_{21}
A10	$\overline{AD_{28}}$	D1	$\overline{WD_0}/\overline{UNC}$	J12	$\overline{BOUT}$	N5	LAD_{18}
A11	$\overline{SPEC_0}$	D2	$\overline{PFETCH}$	J13	$\overline{COM}$	N6	LAD_{15}
A12	$\overline{SPEC_3}$	D3	V_{SS}	J14	$\overline{AD_8}$	N7	LAD_{12}
A13	$\overline{SPEC_5}$	D12	$\overline{ARB_0}$	K1	LAD_{28}	N8	LAD_{10}
A14	V_{CC}	D13	$\overline{AD_0}$	K2	LAD_{26}	N9	LAD_6
B1	V_{SS}	D14	$\overline{AD_5}$	K3	LAD_{27}	N10	LAD_2
B2	$\overline{IAC_0}/\overline{ERR}$	E1	$\overline{CW}/\overline{DEN}$	K12	$\overline{BERL_1}$	N11	CLK2
B3	$\overline{IAC_1}/\overline{FRF}$	E2	$\overline{WY_0}/\overline{COR}$	K13	$\overline{AD_{14}}$	N12	LAD_0
B4	$\overline{AD_{17}}$	E3	$\overline{WY_1}$/MEM	K14	$\overline{AD_{10}}$	N13	RESET
B5	$\overline{AD_{18}}$	E12	$\overline{AD_3}$	L1	$\overline{ALE}$	N14	V_{SS}
B6	$\overline{AD_{19}}$	E13	$\overline{AD_7}$	L2	$\overline{ADS}$	P1	V_{CC}
B7	$\overline{AD_{23}}$	E14	$\overline{ARB_3}$	L3	HOLD	P2	V_{SS}
B8	$\overline{AD_{27}}$	F1	$\overline{BE_3}$	L12	V_{SS}	P3	LAD_{19}
B9	$\overline{SPEC_1}$	F2	$\overline{BE_2}$	L13	$\overline{CHK_0}$	P4	LAD_{17}
B10	$\overline{AD_{31}}$	F3	$\overline{CR}/DT/\overline{R}$	L14	$\overline{MODCHK}$	P5	LAD_{16}
B11	$\overline{SPEC_4}$	F12	$\overline{AD_6}$	M1	HLDA	P6	LAD_{14}
B12	$\overline{RPYDEF}$	F13	$\overline{AD_9}$	M2	LAD_{25}	P7	LAD_{11}
B13	V_{SS}	F14	$\overline{ARB_1}$	M3	$\overline{BADAC}$	P8	LAD_9
B14	V_{SS}	G1	$W/\overline{R}$	M4	V_{SS}	P9	LAD_7
C1	$\overline{SSBUSY}$	G2	$\overline{BE_0}$	M5	V_{CC}	P10	LAD_5
C2	$\overline{WD_1}/\overline{ECC}$	G3	$\overline{LOCK}$	M6	LAD_{20}	P11	LAD_4
C3	$\overline{LERL_0}$	G12	$\overline{AD_{11}}$	M7	LAD_{13}	P12	LAD_1
C4	V_{CC}	G13	$\overline{AD_{12}}$	M8	LAD_8	P13	V_{SS}
C5	V_{SS}	G14	$\overline{AD_2}$	M9	LAD_3	P14	V_{CC}

Table 13. M82965 Pinout—In Signal Order

Signal	PGA Pin	Signal	PGA Pin	Signal	PGA Pin	Signal	PGA Pin
$\overline{AD_0}$	D13	$\overline{ALE}$	L1	LAD_8	M8	$\overline{SPEC_0}$	A11
$\overline{AD_1}$	C14	$\overline{ARB_0}$	D12	LAD_9	P8	$\overline{SPEC_1}$	B9
$\overline{AD_2}$	G14	$\overline{ARB_1}$	F14	LAD_{10}	N8	$\overline{SPEC_2}$	C9
$\overline{AD_3}$	E12	$\overline{ARB_2}$	C13	LAD_{11}	P7	$\overline{SPEC_3}$	A12
$\overline{AD_4}$	H14	$\overline{ARB_3}$	E14	LAD_{12}	N7	$\overline{SPEC_4}$	B11
$\overline{AD_5}$	D14	$\overline{BADAC}$	M3	LAD_{13}	M7	$\overline{SPEC_5}$	A13
$\overline{AD_6}$	F12	$\overline{BE_0}$	G2	LAD_{14}	P6	$\overline{SSBUSY}$	C1
$\overline{AD_7}$	E13	$\overline{BE_1}$	H3	LAD_{15}	N6	V_{CC}	A14
$\overline{AD_8}$	J14	$\overline{BE_2}$	F2	LAD_{16}	P5	V_{CC}	C4
$\overline{AD_9}$	F13	$\overline{BE_3}$	F1	LAD_{17}	P4	V_{CC}	C10
$\overline{AD_{10}}$	K14	$\overline{BERL_0}$	M13	LAD_{18}	N5	V_{CC}	M5
$\overline{AD_{11}}$	G12	$\overline{BERL_1}$	K12	LAD_{19}	P3	V_{CC}	M11
$\overline{AD_{12}}$	G13	$\overline{BOUT}$	J12	LAD_{20}	M6	V_{CC}	P1
$\overline{AD_{13}}$	H12	CACHE	J3	LAD_{21}	N4	V_{CC}	P14
$\overline{AD_{14}}$	K13	$\overline{CHK_0}$	L13	LAD_{22}	N3	V_{REF}	M12
$\overline{AD_{15}}$	H13	$\overline{CHK_1}$	M14	LAD_{23}	N1	V_{SS}	A2
$\overline{AD_{16}}$	A4	CLK2	N11	LAD_{24}	N2	V_{SS}	B1
$\overline{AD_{17}}$	B4	$\overline{COM}$	J13	LAD_{25}	M2	V_{SS}	B13
$\overline{AD_{18}}$	B5	$\overline{CR}$/DT/$\overline{R}$	F3	LAD_{26}	K2	V_{SS}	B14
$\overline{AD_{19}}$	B6	CW/$\overline{DEN}$	E1	LAD_{27}	K3	V_{SS}	C5
$\overline{AD_{20}}$	A5	HLDA	M1	LAD_{28}	K1	V_{SS}	C11
$\overline{AD_{21}}$	A6	HOLD	L3	LAD_{29}	J1	V_{SS}	D3
$\overline{AD_{22}}$	C6	$\overline{IAC_0}$/$\overline{ERR}$	B2	LAD_{30}	H1	V_{SS}	L12
$\overline{AD_{23}}$	B7	$\overline{IAC_1}$/$\overline{FRF}$	B3	LAD_{31}	J2	V_{SS}	M4
$\overline{AD_{24}}$	C7	$\overline{INITID}$	C12	$\overline{LERL_0}$	C3	V_{SS}	M10
$\overline{AD_{25}}$	A7	LAD_0	N12	$\overline{LERL_1}$	A1	V_{SS}	N14
$\overline{AD_{26}}$	A9	LAD_1	P12	$\overline{LOCK}$	G3	V_{SS}	P2
$\overline{AD_{27}}$	B8	LAD_2	N10	$\overline{MODCHK}$	L14	V_{SS}	P13
$\overline{AD_{28}}$	A10	LAD_3	M9	$\overline{PFETCH}$	D2	$\overline{WD_0}$/$\overline{UNC}$	D1
$\overline{AD_{29}}$	C8	LAD_4	P11	$\overline{POPQUE}$	A3	$\overline{WD_1}$/$\overline{ECC}$	C2
$\overline{AD_{30}}$	A8	LAD_5	P10	$\overline{READY}$	H2	W/$\overline{R}$	G1
$\overline{AD_{31}}$	B10	LAD_6	N9	RESET	N13	$\overline{WY_0}$/$\overline{COR}$	E2
$\overline{ADS}$	L2	LAD_7	P9	$\overline{RPYDEF}$	B12	$\overline{WY_1}$/MEM	E3

5

Package Dimensions and Mounting

The MG82965 BXU is packaged in either a 132-lead ceramic pin-grid array (PGA) or a 164-pin CQP package. (Contact factory for details on CQP availability.) Pins in the PGA package are arranged 0.100 inch (2.54 mm) center-to-center, in a 14 by 14 matrix, three rows around. See Figure 19.

A wide variety of available sockets allows low-insertion or zero-insertion force mountings, and a choice of terminals such as soldertail, surface mount, or wire-wrap. Figure 20 shows several applicable sockets.

Package Thermal Specification

The M82965 BXU is specified for operation when its case temperature is within the range of −55°C to +125°C. The PGA case temperature should be measured at the center of the top surface opposite the pins as shown in Figure 21.

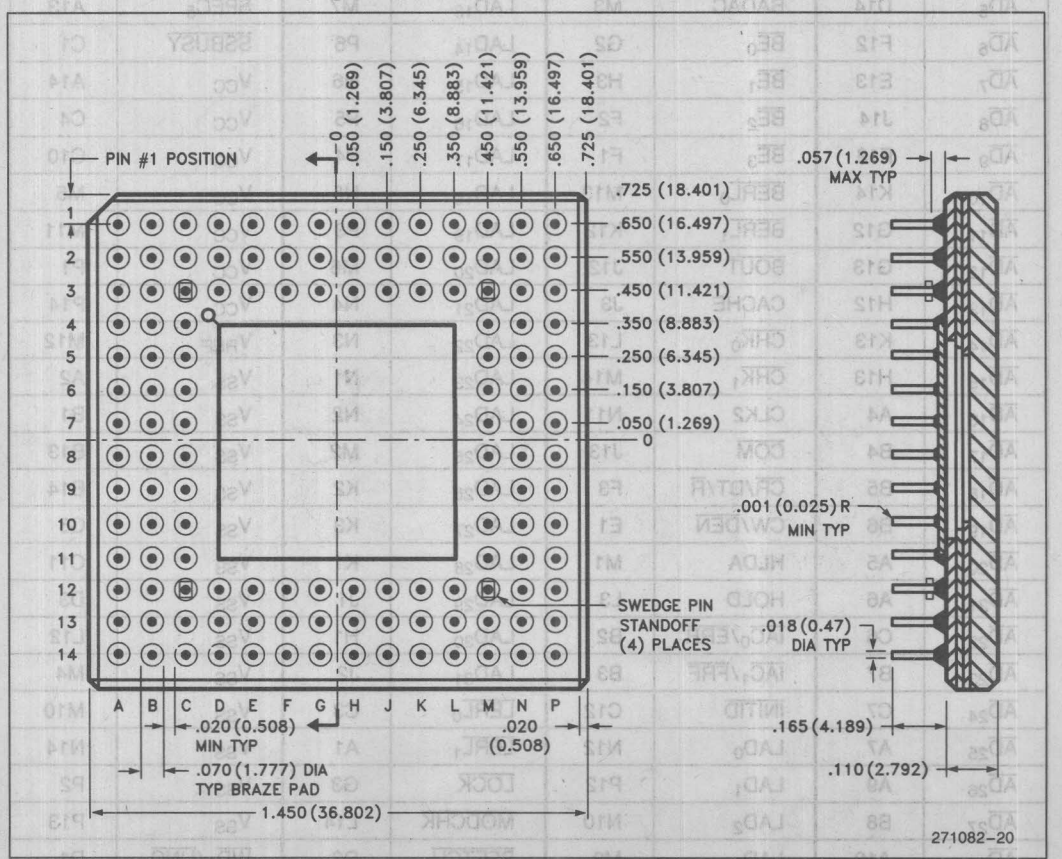


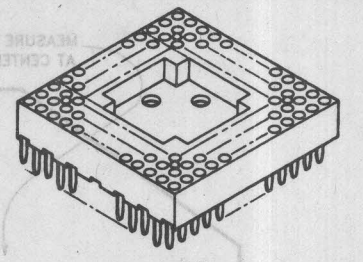
Figure 19. A 132-Lead Pin-Grid Array (PGA) Used to Package the MG82965 BXU

- Low insertion force (LIF) soldertail 55274-1
- Amp tests indicate 50% reduction in insertion force compared to machined sockets

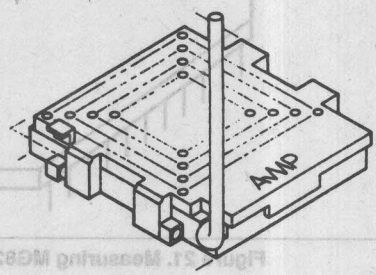
Other socket options

- Zero insertion force (ZIF) soldertail 55583-1
- Zero insertion force (ZIF) Burn-in version 55573-2

Amp Incorporated
(Harrisburg, PA 17105 U.S.A
Phone 717-564-0100)



Amp LIF Socket
55274-1



Amp LIF Socket

271082-21

Cam handle locks in low profile position when MG82965 is installed (handle UP for open and DOWN for closed positions).

Courtesy Amp Incorporated

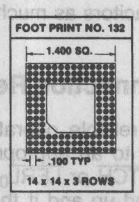
Peel-A-Way* and Kapton Socket Terminal Carriers

- Low insertion force surface mount CS132-37TG
- Low insertion force soldertail CS132-01TG
- Low insertion force wire-wrap CS132-02TG (two-level) CS132-03TG (three-level)
- Low insertion force press-fit CS132-05TG

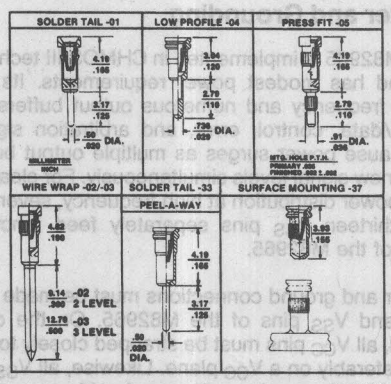
Advanced Interconnections
(5 Division Street)
Warwick, RI 02818 U.S.A.
Phone 401-885-0485)

Peel-A-Way Carrier No. 132:
Kapton Carrier is KS132
Mylar Carrier is MS132

Molded Plastic Body KS132 is shown below:



271082-22



271082-23

Courtesy Advanced Interconnections
(Peel-A-Way Terminal Carriers
U.S. Patent No. 4442938)

*Peel-A-Way is a trademark of Advanced Interconnections.

Figure 20. Several Socket Options for Mounting the M82965 BXU

5

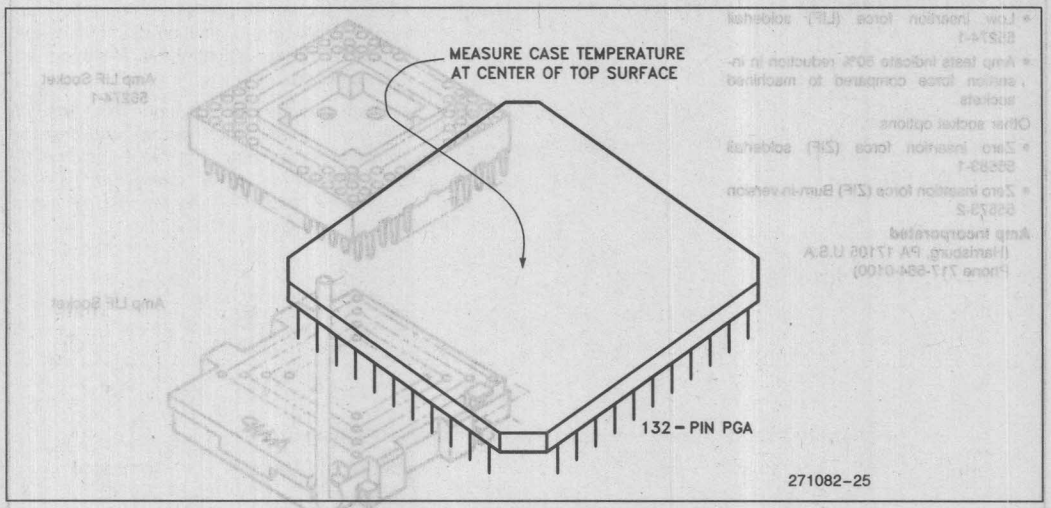


Figure 21. Measuring MG82965 Case Temperature

ELECTRICAL SPECIFICATIONS

Power and Grounding

The M82965 is implemented in CHMOS III technology and has modest power requirements. Its high clock frequency and numerous output buffers (address/data, control, error, and arbitration signals) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, seven V_{CC} and thirteen V_{SS} pins separately feed functional units of the M82965.

Power and ground connections must be made to all V_{CC} and V_{SS} pins of the M82965. On the circuit board, all V_{CC} pins must be strapped closely together, preferably on a V_{CC} plane. Likewise, all V_{SS} pins should be strapped together, preferably on a ground plane.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the M82965. The BXU when driving its two 32-bit address/data buses (AP-Bus and L-Bus) can cause transient power surges, particularly when driving large capacitive loads.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the BXU and decoupling capacitors as much as possible.

Connection Recommendations

For reliable operation, always connect unused inputs to an appropriate signal level. In particular, if $\overline{PFETCH}$ or $\overline{LERL}_{0-1}$ are not used, they should be pulled up and if the CACHE input is not used (i.e., BXU operating in the Memory mode) it should be tied low through a 10 kΩ resistor. No inputs should ever be left floating.

All open-drain outputs require a pullup device. While in most cases a simple pullup resistor will be adequate, a network of pullup and pulldown resistors biased to a valid V_{IH} (e.g., 3.5V) will limit noise and AC power consumption, especially on the AP-Bus.

ABSOLUTE MAXIMUM RATINGS*

Case Temperature under Bias(1) ..... −55°C to +125°C Case
Storage Temperature ..... −65°C to +150°C
Voltage on Any Pin ..... −0.5V to V_{CC} + 0.5V
Power Dissipation 2.5W

NOTICE: This data sheet contains information on products in the sampling and initial production phases of development. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

Operating Conditions

Symbol	Description	Min	Max	Units
T_C	Case Temperature (Instant On)	−55	+125	°C
V_{CC}	Digital Supply Voltage	4.75	5.25	V

Table 14. D.C. Characteristics (Over Specified Operating Conditions)

Symbol	Parameter	Min	Max	Units	Comments
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{ILA}	Input Low Voltage: AP-Bus	−0.5	+1.0	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{IHA}	Input High Voltage: AP-Bus	2.0	V_{CC}	V	
$V_{REF/C}$	V_{REF} Trip Point Cold Start	V_{CC} − 0.7		V	
$V_{REF/W}$	V_{REF} Trip Point Warm Start	1.7	1.8	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+1.0	V	
V_{CH}	CLK2 Input High Voltage	0.55 V_{CC}	V_{CC}	V	
V_{OL}	Output Low Voltage: I_{OL} = 4 mA: LAD Lines I_{OL} = 5 mA: Controls(2) I_{OL} = 25 mA: L-Bus Open-Drain Outputs I_{OL} = 80 mA: AP-Bus Open-Drain Outputs		 0.45 0.45 0.45 0.70	 V V V V	
V_{OH}	Output High Voltage: I_{OH} = 1 mA: LAD Lines I_{OH} = 0.9 mA: Controls(2) I_{OH} = 5.0 mA: ALE	 2.4 2.4 2.4		 V V V	
I_{CC}	Power Supply Current		450	mA	
I_{LI}	Input Leakage Current		±15	μA	$0V \le V_O \le V_{CC}$
I_{LO}	Output Leakage Current		±15	μA	$0.45V \le V_O \le V_{CC}$
C_{IN}	Input Capacitance		10	pF	Note 1
C_O	I/O or Output Capacitance		12	pF	Note 1
C_{CLK}	Clock Capacitance		12	pF	Note 1

NOTES:
1. Test frequency = 1 MHz, T_C = 25°C, unmeasured pins at GND.
2. "Controls" include all L-Bus I/O pins not otherwise specified.

5

Table 14. D.C. Characteristics (Over Specified Operating Conditions)

Symbol	Parameter	Min	Max	Units	Comments
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{ILA}	Input Low Voltage: AP-Bus	−0.5	+ 1.0	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{IHA}	Input High Voltage: AP-Bus	2.0	V_{CC}	V	
$V_{REF/C}$	V_{REF} Trip Point Cold Start		V_{CC} − 0.7	V	
$V_{REF/W}$	V_{REF} Trip Point Warm Start	1.7	1.8	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+ 1.0	V	
V_{CH}	CLK2 Input High Voltage	0.85 V_{CC}	V_{CC}	V	
V_{OL}	Output Low Voltage: I_{OL} = 4 mA: LAD Lines I_{OL} = 5 mA: Control(S) I_{OL} = 25 mA: L-Bus Open-Drain Outputs I_{OL} = 80 mA: AP-Bus Open-Drain Outputs		0.45 0.45 0.45 0.70	V V V V	
V_{OH}	Output High Voltage: I_{OH} = 1 mA: LAD Lines I_{OH} = 0.8 mA: Control(S) I_{OH} = 5.0 mA: ALE	2.4 2.4 2.4		V V V	
I_{CC}	Power Supply Current		480	mA	
I_{IL}	Input Leakage Current		± 15	µA	0V ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		± 15	µA	0.45V ≤ V_O ≤ V_{CC}
C_{IN}	Input Capacitance		10	pF	Note 1
$C_{I/O}$	I/O or Output Capacitance		12	pF	Note 1
C_{CLK}	Clock Capacitance		12	pF	Note 1

NOTES:
1. Test frequency = 1 MHz, T_C = 25°C, unmeasured pins at GND.
2. "Control" include all L-Bus I/O pins not otherwise specified.

Table 15. M82965 A.C. Timing Specifications (Over Specified Operating Conditions)

Symbol	Parameter	Min	Max	Units	Comments
T_1	Clock Period	31.25	125	ns	V_{IN} = 1.5V
T_2	Clock Low Time	11		ns	V_{IN} = 10% Point = 1.2V
T_3	Clock High Time	11		ns	V_{IN} = 90% Point = 0.1V + 0.5 V_{CC}
T_4	Clock Fall Time		10	ns	V_{IN} = 90% Point to 10% Point
T_5	Clock Rise Time		10	ns	V_{IN} = 10% Point to 90% Point
T_6	Output Valid Delay:				
	LAD	4	35	ns	C_L = 100 pF
	$\overline{WY}$	4	35	ns	C_L = 125 pF
	$\overline{CW}$, $\overline{WD}$, SS Busy	4	30	ns	C_L = 75 pF
	$\overline{CR}$	4	45	ns	C_L = 75 pF
	Controls(1)	2	35	ns	C_L = 75 pF
T_7	$\overline{ALE}$ Width	15		ns	C_L = 75 pF
T_8	$\overline{ALE}$ Invalid Delay		20	ns	C_L = 75 pF
T_9	Output Float Delay:				
	LAD	5	20	ns	C_L = 100 pF
	$\overline{WY}$	5	22	ns	C_L = 125 pF
	Controls(1)	5	22	ns	C_L = 75 pF
T_{10}	Input Setup Time:				
	$\overline{LOCK}$, HOLD, HOLDAR, $\overline{READY}$	8		ns	10% Point
	$\overline{ECC}$, $\overline{UNC}$	15		ns	10% Point
	Controls(1)	3		ns	10% Point
T_{11}	Input Data Hold	10		ns	90% Point
T_{12}	Setup to $\overline{ALE}$ Inactive	10		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{13}	Hold after $\overline{ALE}$ Inactive	8		ns	C_L = 100 pF (LAD) C_L = 75 pF (Controls)
T_{14}	RESET Hold	5		ns	
T_{15}	RESET Setup	8		ns	
T_{16}	RESET Width	1250		ns	40 CLK2 Periods Minimum
T_{17}	Clock to Data Valid (AP-Bus)		17	ns	C_L = 50 pF I_{OL} = 50 mA
T_{18}	Clock to High Impedance (AP-Bus)		14	ns	
T_{19}	Output Hold (AP-Bus)	5		ns	C_L = 50 pF I_{OL} = 50 mA
T_{20}	Input Setup (AP-Bus)	7		ns	
T_{21}	Input Hold (AP-Bus)	10		ns	

NOTE:
1. "Controls" include all L-Bus I/O pins not otherwise specified.

5

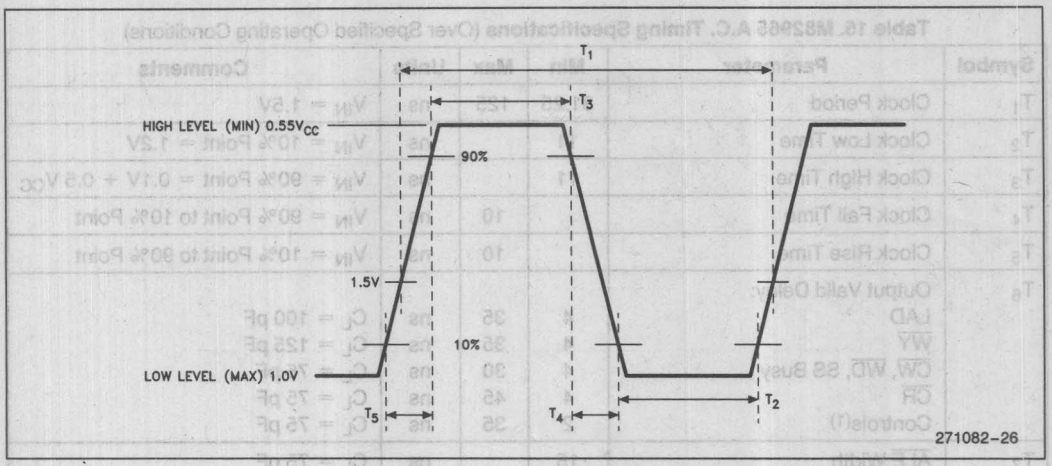
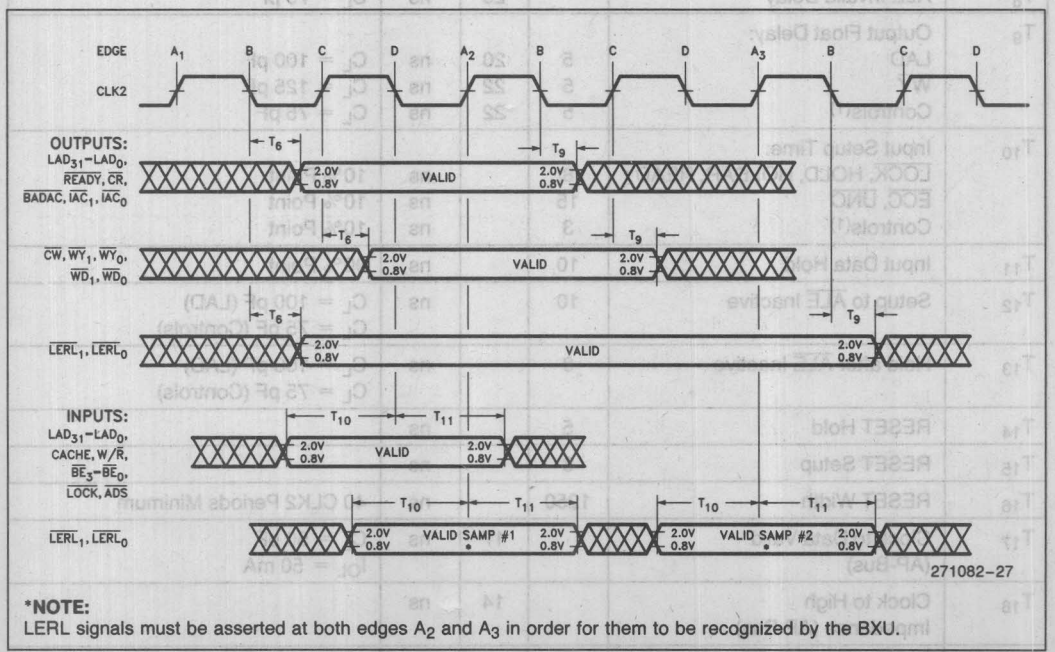
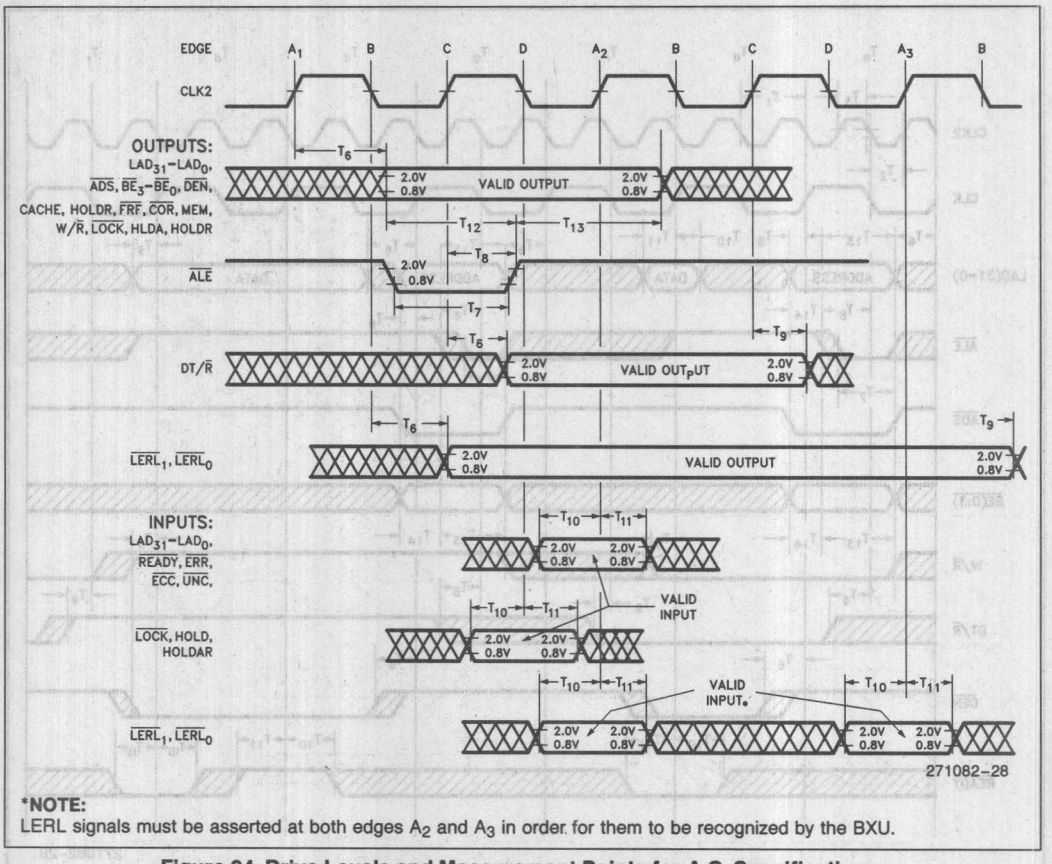


Figure 22. CLK2 Timing



***NOTE:**
LERL signals must be asserted at both edges A_2 and A_3 in order for them to be recognized by the BXU.

Figure 23. Drive Levels and Measurement Points for A.C. Specifications. L-Bus Timings for the BXU as a Bus Slave



***NOTE:**
LERL signals must be asserted at both edges A_2 and A_3 in order for them to be recognized by the BXU.

Figure 24. Drive Levels and Measurement Points for A.C. Specifications. L-Bus Timings for the BXU as a Bus Master

5

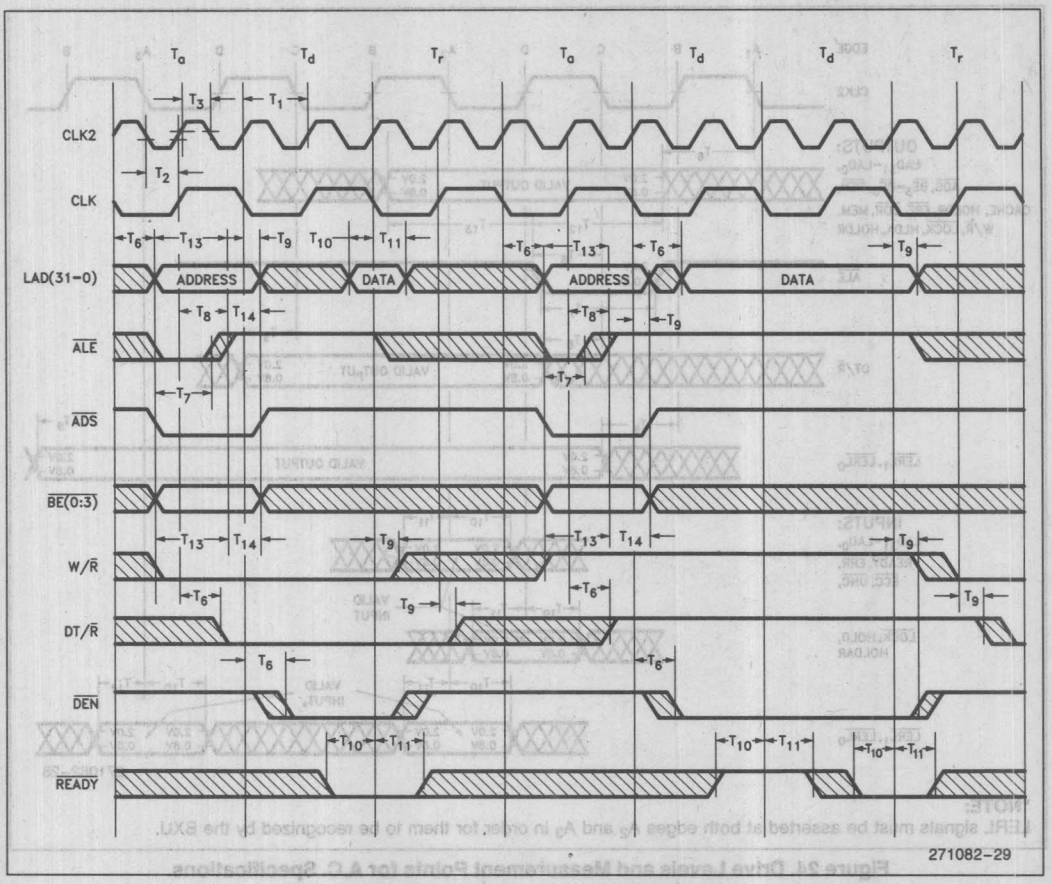
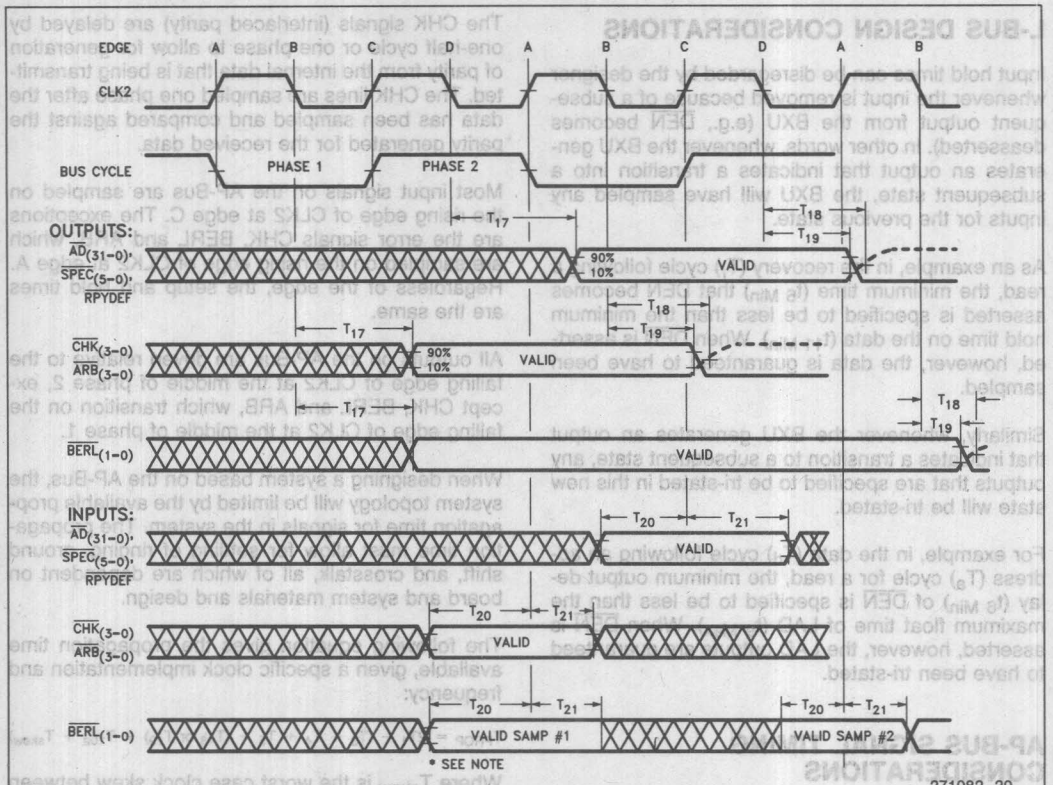


Figure 25. Relative Timing for L-Bus Signals



*NOTE:
BERL signals must be asserted at both edges A_2 and A_3 in order for them to be recognized by the BXU.

Figure 26. Relative Timing for AP-Bus Signals

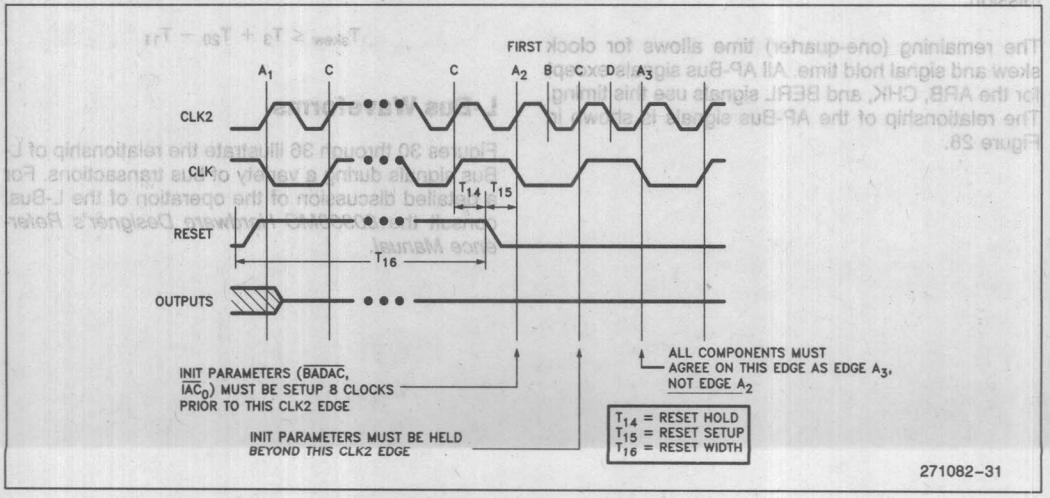


Figure 27. RESET Setup and HOLD Timing

L-BUS DESIGN CONSIDERATIONS

Input hold times can be disregarded by the designer whenever the input is removed because of a subsequent output from the BXU (e.g., $\overline{DEN}$ becomes deasserted). In other words, whenever the BXU generates an output that indicates a transition into a subsequent state, the BXU will have sampled any inputs for the previous state.

As an example, in the recovery (T_r) cycle following a read, the minimum time ($t_{6\ Min}$) that $\overline{DEN}$ becomes asserted is specified to be less than the minimum hold time on the data ($t_{11\ Min}$). When $\overline{DEN}$ is asserted, however, the data is guaranteed to have been sampled.

Similarly, whenever the BXU generates an output that indicates a transition to a subsequent state, any outputs that are specified to be tri-stated in this new state will be tri-stated.

For example, in the data (T_d) cycle following an address (T_a) cycle for a read, the minimum output delay ($t_{6\ Min}$) of $\overline{DEN}$ is specified to be less than the maximum float time of LAD ($t_{9\ Max}$). When $\overline{DEN}$ is asserted, however, the LAD outputs are guaranteed to have been tri-stated.

AP-BUS SIGNAL TIMING CONSIDERATIONS

The AP-Bus uses three-quarter cycle signaling for data transmission. Data is driven on edge D and sampled on edge C. This approach allows three-quarters of the bus cycle to be used for data transmission.

The remaining (one-quarter) time allows for clock skew and signal hold time. All AP-Bus signals except for the ARB, CHK, and BERL signals use this timing. The relationship of the AP-Bus signals is shown in Figure 28.

The CHK signals (interlaced parity) are delayed by one-half cycle or one phase to allow for generation of parity from the internal data that is being transmitted. The CHK lines are sampled one phase after the data has been sampled and compared against the parity generated for the received data.

Most input signals on the AP-Bus are sampled on the rising edge of CLK2 at edge C. The exceptions are the error signals CHK, BERL and ARB, which are sampled on the rising edge of CLK2 at edge A. Regardless of the edge, the setup and hold times are the same.

All outputs on the AP-Bus are driven relative to the falling edge of CLK2 at the middle of phase 2, except CHK, BERL and ARB, which transition on the falling edge of CLK2 at the middle of phase 1.

When designing a system based on the AP-Bus, the system topology will be limited by the available propagation time for signals in the system. The propagation time must allow for settling of ringing, ground shift, and crosstalk, all of which are dependent on board and system materials and design.

The following equation gives the propagation time available, given a specific clock implementation and frequency:

$$T_{PROP} = 2T_1 - (T_3 + T_4 + T_5 + (T_{18} \text{ or } T_{19}) + T_{10a} + T_{skew})$$

Where T_{skew} is the worst case clock skew between BXUs (clock skew is the time delay between any two clocks in the system due to physical distribution limits).

In AP-Bus systems, this skew is defined as follows:

$$T_{skew} \leq T_3 + T_{20} - T_{11}$$

L-Bus Waveforms

Figures 30 through 36 illustrate the relationship of L-Bus signals during a variety of bus transactions. For a detailed discussion of the operation of the L-Bus, consult the *80960MC Hardware Designer's Reference Manual*.

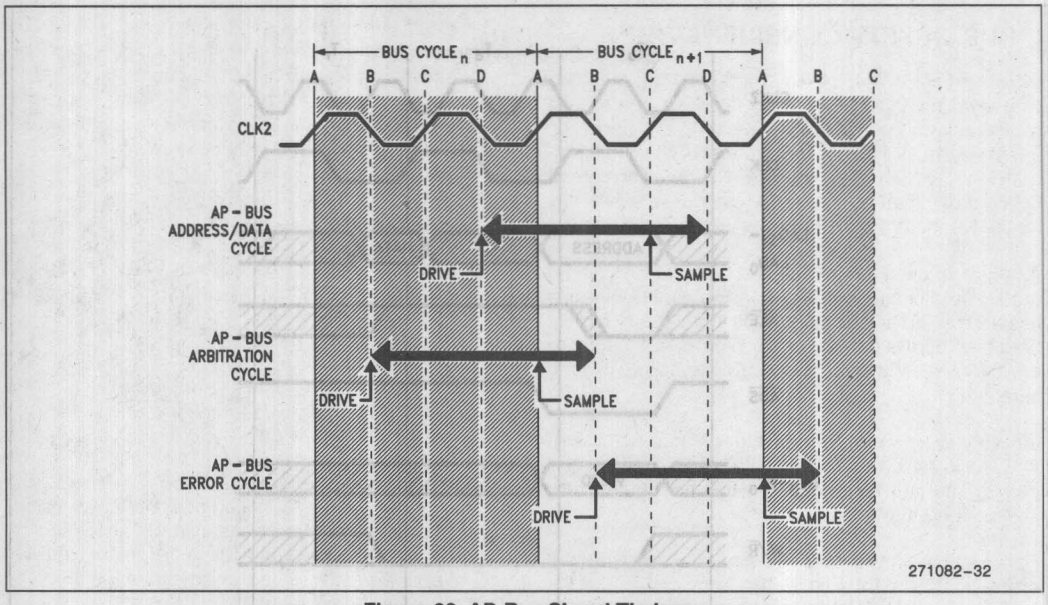


Figure 28. AP-Bus Signal Timing

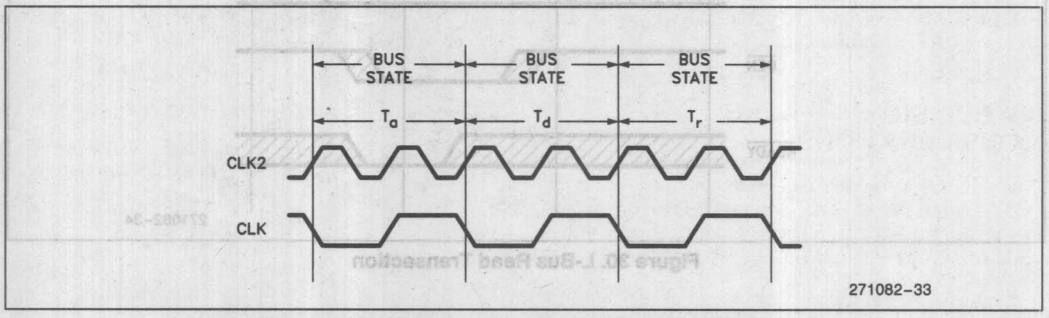


Figure 29. System and Processor Clock Relationship

5

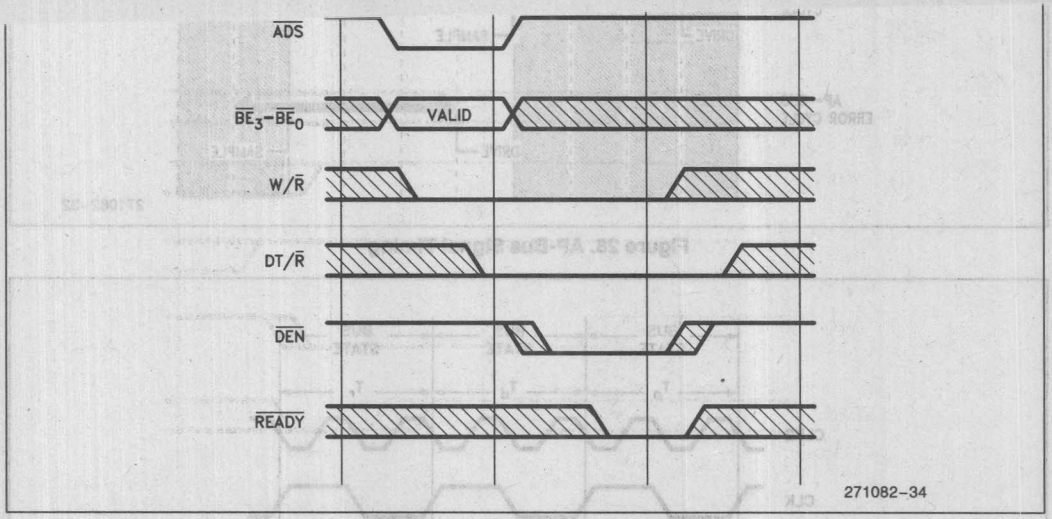


Figure 30. L-Bus Read Transaction

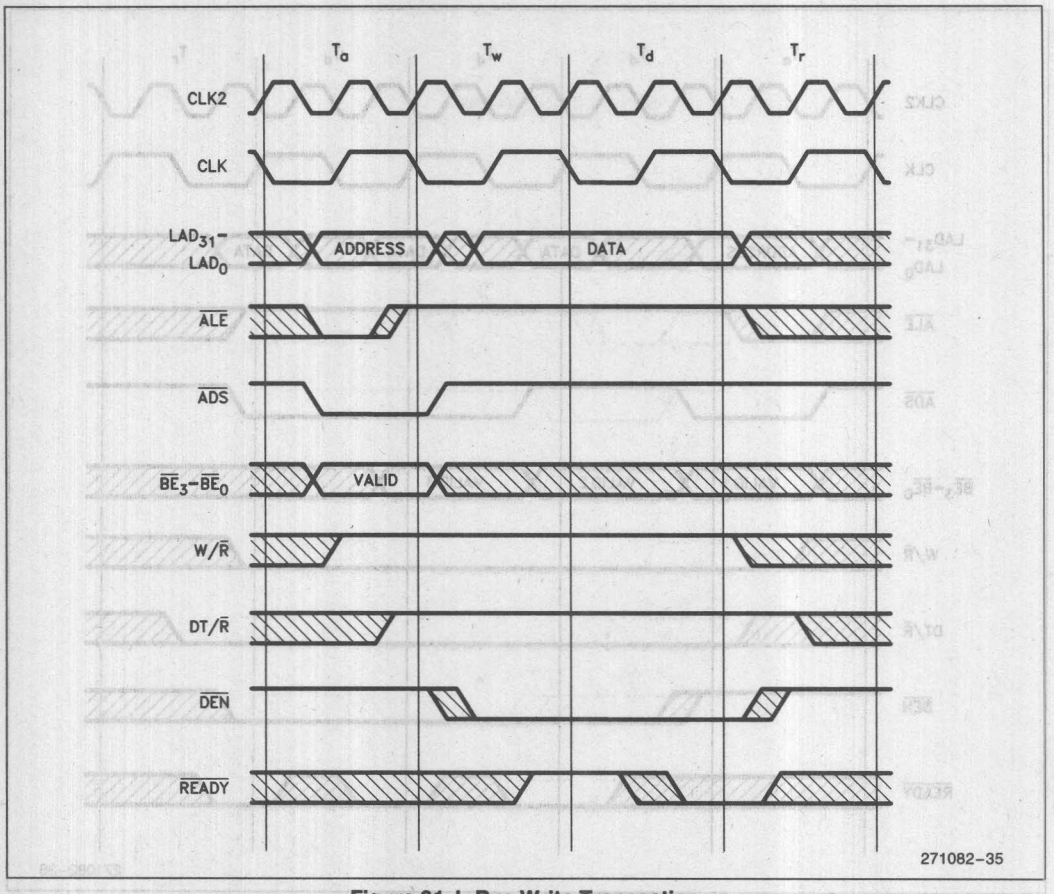


Figure 31. L-Bus Write Transaction

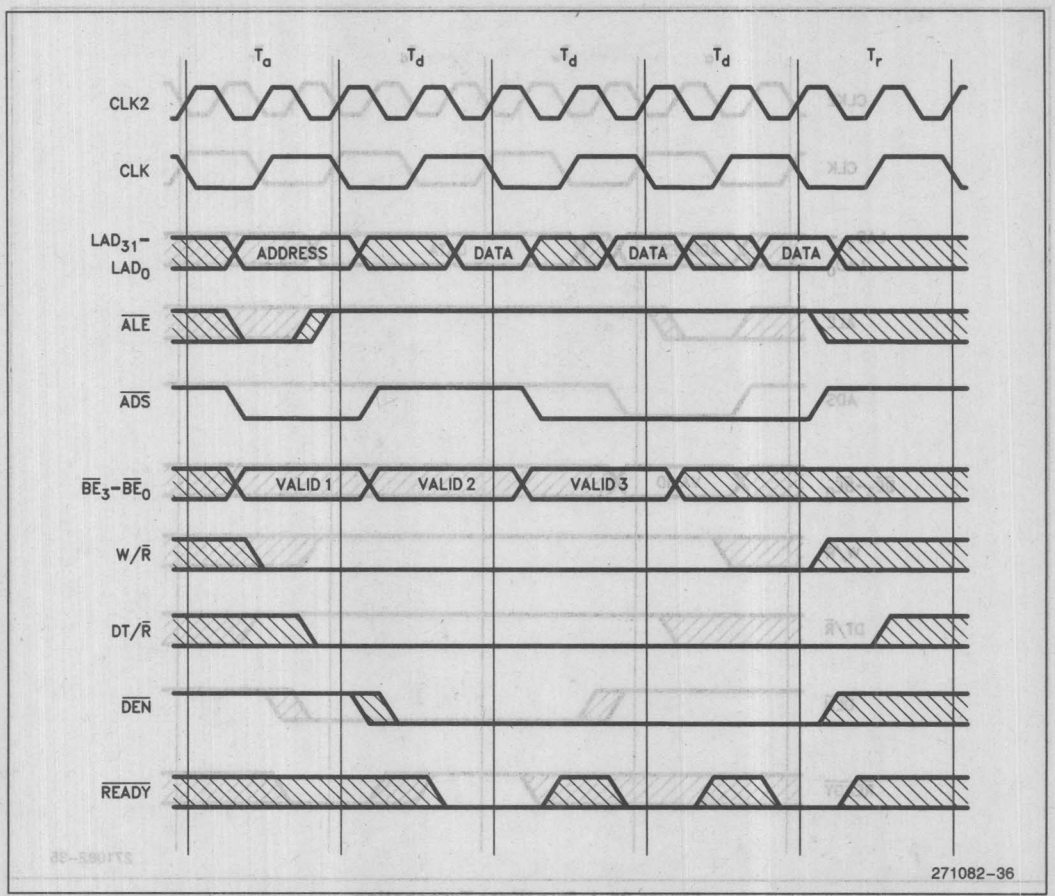


Figure 32. L-Bus Burst Read Transaction

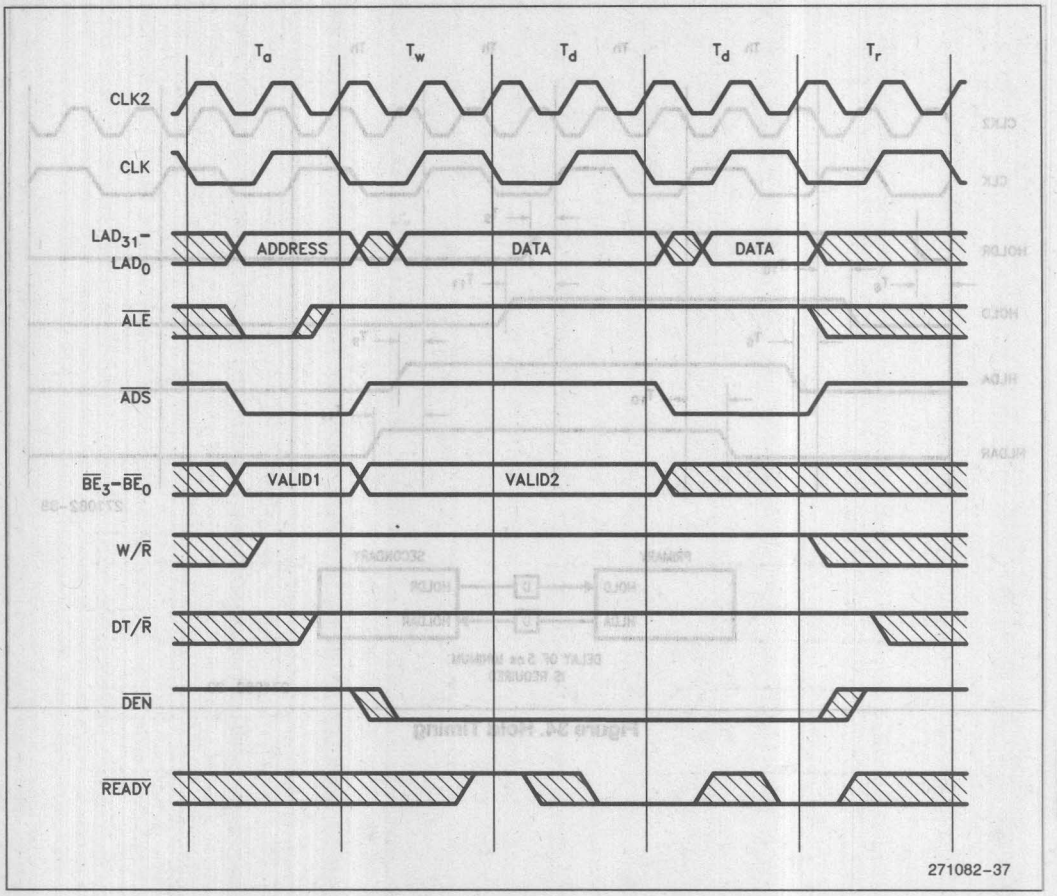


Figure 33. L-Bus Burst Write Transaction with One Wait State

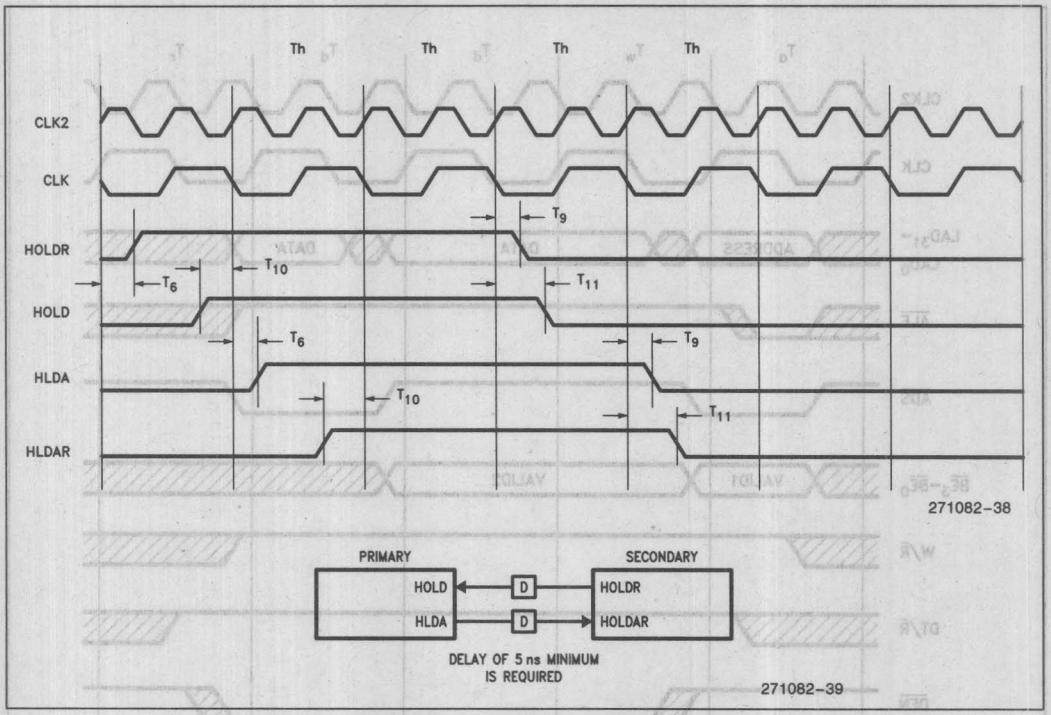


Figure 34. Hold Timing

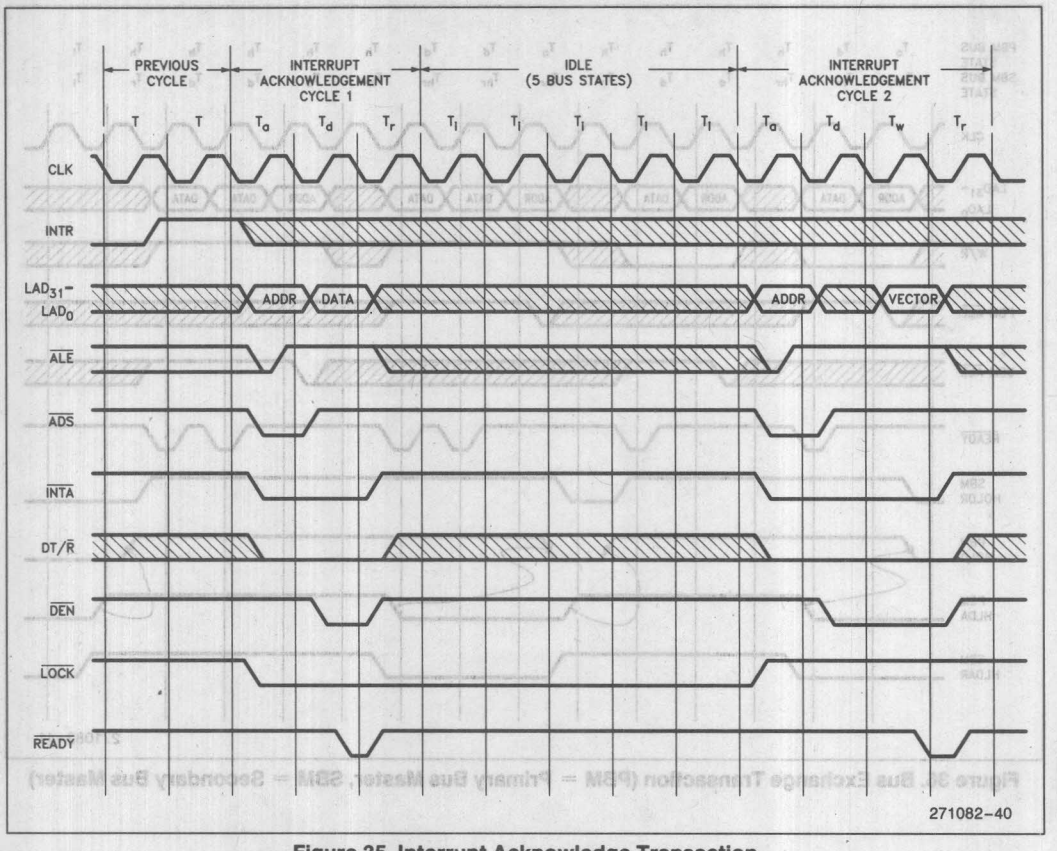


Figure 35. Interrupt Acknowledge Transaction

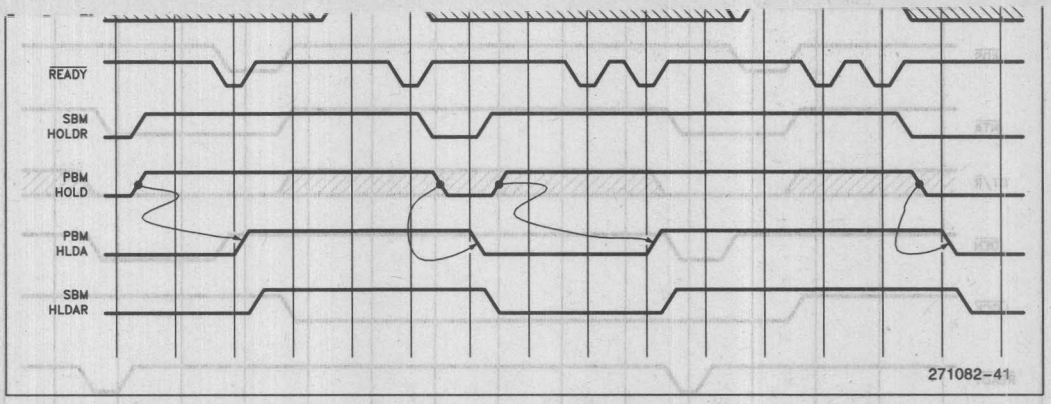


Figure 36. Bus Exchange Transaction (PBM = Primary Bus Master, SBM = Secondary Bus Master)

80960SA/SB Data Sheet

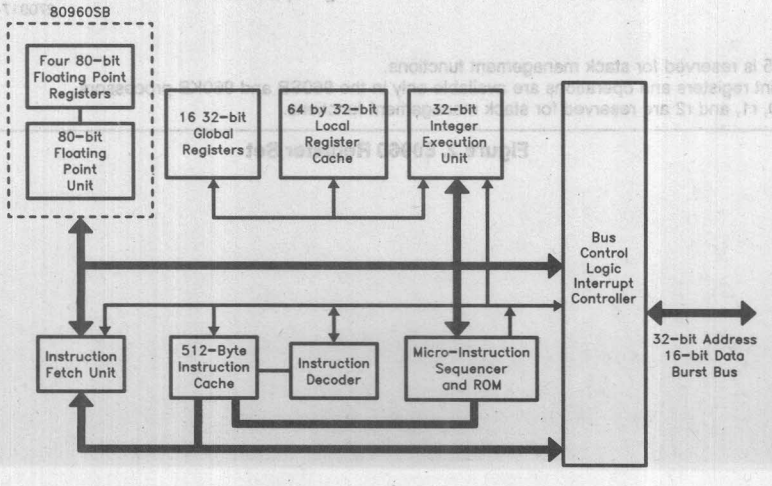
6

80960SA/80960SB EMBEDDED 32-BIT PROCESSORS WITH 16-BIT BURST DATA BUS

- **High-Performance Embedded Architecture**
  - **16 MIPS Burst Execution at 16 MHz**
  - **5 MIPS* Sustained Execution at 16 MHz**
- **512-Byte On-Chip Instruction Cache**
  - **Direct Mapped**
  - **Parallel Load/Decode for Uncached Instructions**
- **Multiple Register Sets**
  - **Sixteen Global 32-Bit Registers**
  - **Sixteen Local 32-Bit Registers**
  - **Four Local Register Sets Stored On-Chip**
  - **Register Scoreboarding**
- **Software Compatible with 80960KA/KB/CA**
- **Built-In Interrupt Controller**
  - **4 Direct Interrupt Pins**
  - **32 Priority Levels 256 Vectors**
  - **Supports 8259A**
- **Built-In Floating Point Unit (80960SB only)**
  - **Fully IEEE 754 Compatible**
- **Easy to Use, High Bandwidth 16-Bit Bus**
  - **25.6 MByte/sec Burst**
  - **Up to 16 Bytes Transferred per Burst**
- **32-Bit Address Space, 4 Gigabytes**
- **80-Lead Quad Flat Pack (EIAJ QFP)**
- **84-Lead Plastic Leaded Chip Carrier (PLCC)**

The 80960SA and 80960SB are members of Intel's i960 32-bit processor family, which are designed especially for low cost embedded applications. They are based on the family's high performance, common core architecture, and include a 512-byte instruction cache and a built-in interrupt controller. The 80960SA and 80960SB have a larger register set, multiple parallel execution units, and a high bandwidth, 16-bit, burst bus. Using advanced RISC technology, these high performance processors are capable of execution rates in excess of 4.2 million instruction per second.* The 80960SA and 80960SB are well-suited for a wide range of cost sensitive embedded applications such as laser printers, EISA and MCA adapters, disk controllers, and X Terminals.

*Relative to Digital Equipment Corporation's VAX-11/780** at MIPS



270917-1

**VAX-11™ is a trademark of Digital Equipment Corporation.

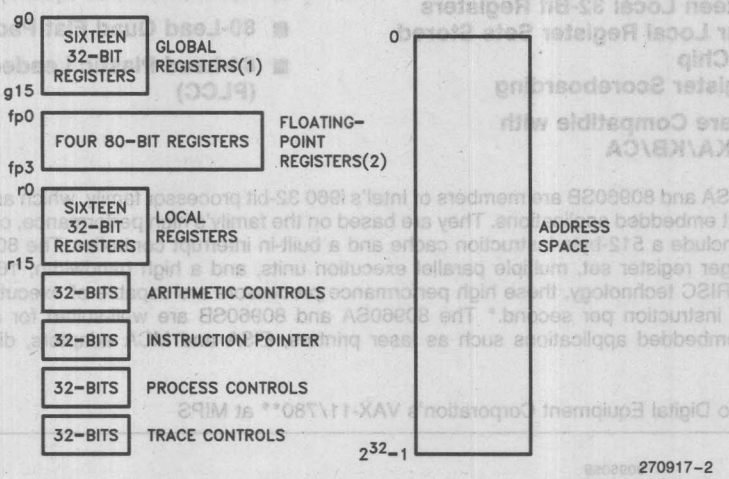
November 1990
Order Number: 270917-001

THE i960 SERIES

The 80960SA and 80960SB are members of a new family of 32-bit microprocessors from Intel known as the i960 Series. This series was especially designed to serve the needs of embedded applications. The embedded market includes applications as diverse as industrial automation, avionics, image processing, graphics, robotics, telecommunications, and automobiles. These types of applications require high integration, low power consumption, quick interrupt response times, and high performance. Since time to market is critical, embedded microprocessors need to be easy to use in both hardware and software designs.

All members of the 80960 series share a common core architecture which utilizes RISC technology so that, except for special functions, the family members are object code compatible. Each new processor in the series will add its own special set of functions to the core to satisfy the needs of a specific application or range of applications for the embedded market. For example, future processors may include a DMA controller, a timer, or an A/D converter.

Software written for the 80960SA and 80960SB will run without modification on any other member of the 80960 family. The 80960SA is pin compatible with the 80960SB, which includes an integrated floating-point unit.



NOTES:
1. Register g15 is reserved for stack management functions.
2. Floating-Point registers and operations are available only in the 960SB and 960KB processors.
3. Registers r0, r1, and r2 are reserved for stack management functions.

Figure 2. 80960 Register Set

Key Performance Features

The 80960SA and 80960SB's architecture is based on the most recent advances in RISC technology and is grounded in Intel's long experience in designing embedded controllers. Many features contribute to the 80960SA and 80960SB exceptional performance.

1. Large Register Set. Modern compilers can take advantage of a large number of registers to optimize execution speed. For maximum flexibility, the 80960SA and 80960SB provide 32 32-bit registers and four 80-bit floating registers. (See Figure 2.)

2. Fast Instruction Execution. Simple functions make up the bulk of instructions in most programs, so that execution speed can be greatly improved by ensuring that these core instructions execute in as short a time as possible. The most-frequently executed instruction such as register-register moves, add/subtract, logical operations, and shifts execute in one to two cycles (Table 1 contains a list of instructions).

3. Load/Store Architecture. Like other processors based on RISC technology, the 80960SA and 80960SB has a Load/Store architecture. Only the LOAD and STORE instructions reference memory; all other instructions operate on registers. This type of architecture simplifies instruction decoding and is used in combination with other techniques to increase parallelism.

4. Simple Instruction Formats. All instructions in the 80960SA and 80960SB are 32 bits long and must be aligned on word boundaries. This alignment makes it possible to eliminate the instruction-alignment stage in the pipeline. To simplify the instruction decoder further, there are only five instruction formats and each instruction uses only one format. (See Figure 3.)

5. Overlapped Instruction Execution. A load operation allows execution of subsequent instructions to continue before the data has been returned from memory, so that these instructions can overlap the load. The 80960SA and 80960SB manage this process transparently to software through the use of a register scoreboard. Conditional instructions also make use of a scoreboard so that subsequent unrelated instructions can be executed while the conditional instruction is pending.

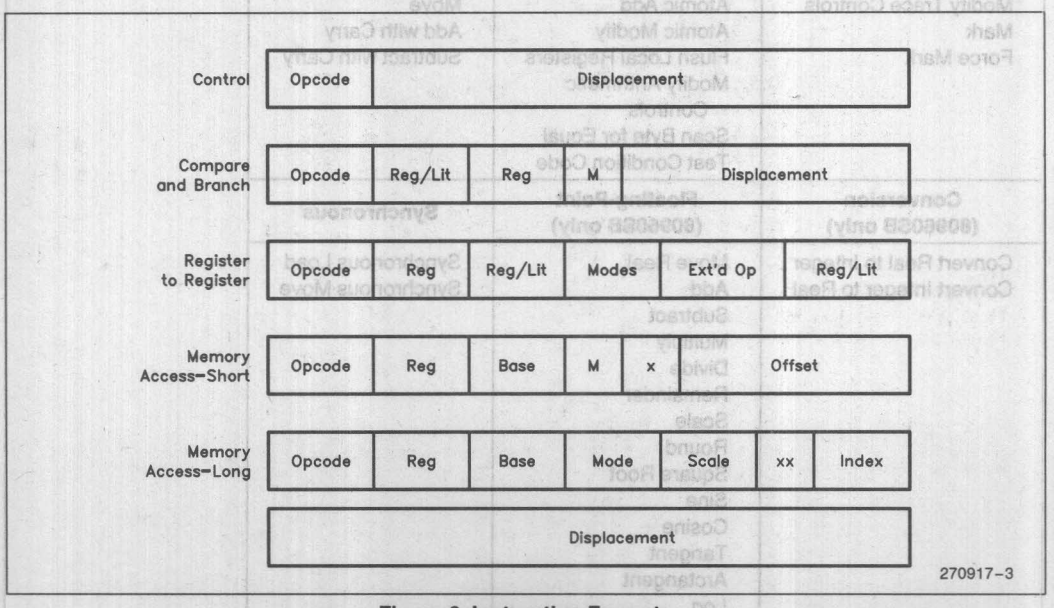


Figure 3. Instruction Formats

Table 1. 80960SA and 80960SB Instruction Set

Data Movement	Arithmetic	Logical	Bit and Bit Field
Load	Add	And	Set Bit
Store	Subtract	Not And	Clear Bit
Move	Multiply	And Not	Not Bit
Load Address	Divide	Or	Check Bit
	Remainder	Exclusive Or	Alter Bit
	Modulo	Not Or	Scan for Bit
	Shift	Or Not	Scan over Bit
	Extended Multiply	Nor	Extract
	Extended Divide	Exclusive Nor	Modify
		Not	
		Nand	
		Rotate	
Comparison	**Branch**	**Call/Return**	**Fault**
Compare	Unconditional Branch	Call	Conditional Fault
Conditional Compare	Conditional Branch	Call Extended	Synchronize Faults
Compare and Increment	Compare and Branch	Call System	
Compare and Decrement		Return	
		Branch and Link	
Debug	**Miscellaneous**	**Decimal**	
Modify Trace Controls	Atomic Add	Move	
Mark	Atomic Modify	Add with Carry	
Force Mark	Flush Local Registers	Subtract with Carry	
	Modify Arithmetic Controls		
	Scan Byte for Equal		
	Test Condition Code		
Conversion (80960SB only)	**Floating-Point (80960SB only)**	**Synchronous**	
Convert Real to Integer	Move Real	Synchronous Load	
Convert Integer to Real	Add	Synchronous Move	
	Subtract		
	Multiply		
	Divide		
	Remainder		
	Scale		
	Round		
	Square Root		
	Sine		
	Cosine		
	Tangent		
	Arctangent		
	Log		
	Log Binary		
	Log Natural		
	Exponent		
	Classify		
	Copy Real Extended		
	Compare		

80960SB are exceptionally insensitive to memory wait states. In fact, each wait state causes only a 10% degradation in system performance. The benefit is that the 80960SA and 80960SB will deliver outstanding performance even with a low cost memory system.

8. Cache Bypass. If there is a cache miss, the processor fetches the needed instruction, then sends it on to the instruction decoder at the same time it updates the cache. Thus, no extra time is taken to load and read the cache.

Memory Space and Addressing Modes

The 80960SA and 80960SB offer a linear programming environment so that all programs running on the processors are contained in a single address space. The maximum size of the address space is 4 Gigabytes.

For ease of use, the 80960SA and 80960SB have a small number of addressing modes, but include all those necessary to ensure efficient compiler implementations of high-level languages such as C, Fortran and Ada. Table 2 lists the memory addressing modes.

Large Register Set

The following environment of the 80960SA and 80960SB include a large number of registers. In fact, 32 registers are available at any time. The availability of this many registers greatly reduces the number of memory accesses required to execute most programs, which leads to greater instruction processing speed.

There are two types of general-purpose registers: local and global. The global registers consist of sixteen 32-bit registers (G0 through G15). These registers perform the same function as the general-purpose registers provided in other popular microprocessors. The term global refers to the fact that these registers retain their contents across procedure calls.

The local registers, on the other hand, are procedure specific. For each procedure call, the 80960SA and 80960SB allocate 16 local registers (R0 through R15). Each local register is 32 bits wide.

Multiple Register Sets

To further increase the efficiency of the register set, multiple sets of local registers are stored on-chip. This cache holds up to four local register frames, which means that up to three procedure calls can be made without having to access the procedure stack resident in memory.

Table 2. Memory Addressing Modes

- 12-Bit Offset
- 32-Bit Offset
- Register-Indirect
- Register + 12-Bit Offset
- Register + 32-Bit Offset
- Register + (Index-Register x Scale-Factor)
- Register x Scale Factor + 32-Bit Displacement
- Register + (Index-Register x Scale-Factor) + 32-Bit Displacement

Scale-Factor is 1, 2, 4, 8 or 16

Although programs may have procedure calls nested many calls deep, a program typically oscillates back and forth between only two or three levels. As a result, with four stack frames in the cache, the probability of there being a free frame on the cache when a call is made is very high. In fact, runs of representative C-language programs show that 80% of the calls are handled without needing to access memory.

If there are four or more active procedures and a new procedure is called, the processor moves the oldest set of local registers in the register cache to a procedure stack in memory to make room for a new set of registers. Global register G15 is used by the processor as the frame pointer (FP) for the procedure stack.

Note that the global registers are not exchanged on a procedure call, but retain their contents, making them available to all procedures for fast parameter passing. An illustration of the register cache is shown in Figure 4.

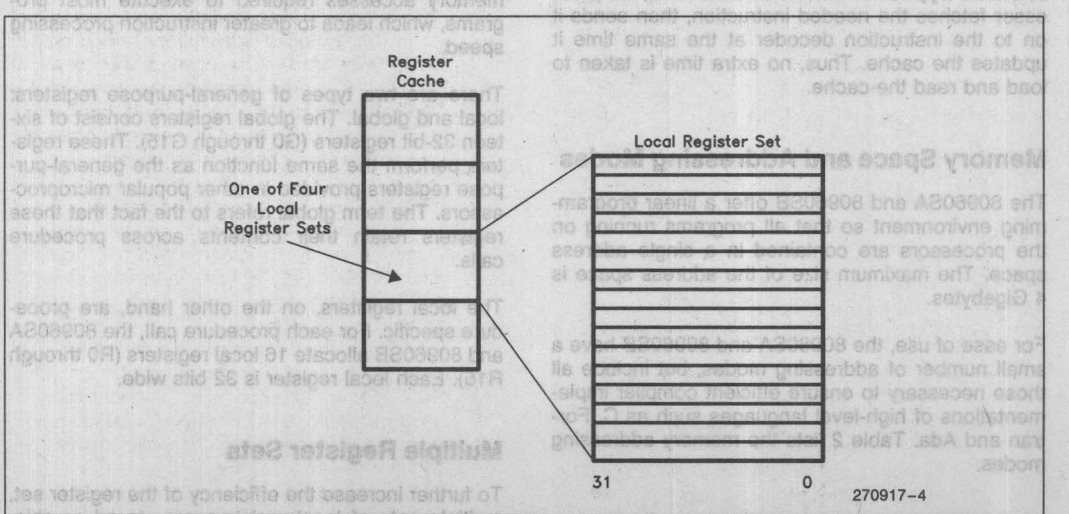


Figure 4. Multiple Register Sets are Stored On-Chip

Instruction Cache

To further reduce memory accesses, the 80960SA and 80960SB include a 512-byte on-chip instruction cache. The instruction cache is based on the concept of locality of reference; that is, most programs are not usually executed in a steady stream but consist of many branches and loops that lead to jumping back and forth within the same small section of code. Thus, by maintaining a block of instructions in a cache, the number of memory references required to read instructions into the processor can be greatly reduced.

To load the instruction cache, instructions are fetched in 16-byte blocks, so that up to four instructions can be fetched at one time. An efficient prefetch algorithm increases the probability that an instruction will already be in the cache when it is needed.

Code for small loops will often fit entirely within the cache, leading to a great increase in processing speed since further memory references might not be necessary until the program exits the loop. Similarly, when calling short procedures, the code for the calling procedure is likely to remain in the cache, so it will be there on the procedure's return.

Register Scoreboarding

The instruction decoder has been optimized in several ways. One of these optimizations is the ability to do instruction overlapping by means of register scoreboarding.

Register scoreboarding occurs when a LOAD instruction is executed to move a variable from memory into a register. When the instruction is initiated, a scoreboard bit on the target register is set. When the register is actually loaded, the bit is reset. In between, any reference to the register contents is accompanied by a test of the scoreboard bit to insure that the load has completed before processing continues. Since the processor does not have to wait for the LOAD to be completed, it can go on to execute additional instructions placed in between the LOAD instruction and the instruction that uses the register contents, as shown in the following example:

```
LOAD address 1, R4
LOAD address 2, R5
Unrelated instruction
Unrelated instruction
ADD R4, R5, R6
```

In essence, the two unrelated instructions between the LOAD and ADD instructions are executed for free (i.e., take no apparent time to execute) because they are executed while the register is being loaded. Up to three instructions can be pending at one time with three corresponding scoreboard bits set. By exploiting this feature, system programmers and compilers have a useful tool for optimizing execution speed.

Floating-Point Arithmetic

In the 80960SB, floating-point arithmetic has been made an integral part of the architecture. Having the floating-point unit integrated on-chip provides two advantages. First, it improves the performance of the chip for floating-point applications, since no additional bus overhead is associated with floating-point calculations, thereby leaving more time for other bus operations such as I/O. Second, the cost of using floating-point operations is reduced because a separate coprocessor chip is not required.

The 80960SB floating-point (real number) data types include single-precision (32-bit), double-precision (64-bit), and extended precision (80-bit) floating-point numbers. Any register may be used to execute floating-point operations.

The processor provides hardware support for both mandatory and recommended portions of IEEE Standard 754 for floating-point arithmetic, exponential, logarithmic, and other transcendental functions. Table 3 shows execution times for some representative instructions.

Table 3. Sample Floating-Point Execution Times (μs) at 16 MHz

	32-Bit	64-Bit
Add	0.6	0.8
Subtract	0.6	0.8
Multiply	1.1	2.0
Divide	2.0	4.5
Square Root	5.8	6.1
Arctangent	15.8	20.5
Exponent	17.7	19.5
Sine	23.8	25.9
Cosine	23.8	25.9

High Bandwidth Bus

The 80960SA and 80960SB CPUs reside on a high-bandwidth address/data bus. The bus provides a direct communication path between the processor and the memory and I/O subsystem interfaces. The processor uses the bus to fetch instructions, manipulate memory, and respond to interrupts. Its features include:

- 16-bit data path multiplexed onto the lower bits of the 32-bit address path
- Eight 16-bit half-word burst capacity, which allows transfers from 1 to 16 bytes at a time
- High bandwidth reads and writes a 25.6 MBytes per second

Figure 5 identifies the groups of signals which constitute the Bus. Table 4 lists the function of the Bus and other processor-support signals, such as the interrupt lines.

Interrupt Handling

The 80960SA and 80960SB can be interrupted in one of two ways: by the activation of one of four interrupt pins or by sending a message on the processor's data bus.

The 80960SA and 80960SB are unusual in that they automatically handle interrupts on a priority basis and track pending interrupts through their on-chip interrupt controller. Two of the interrupt pins can be configured to provide 8259A handshaking for expansion beyond four interrupt lines.

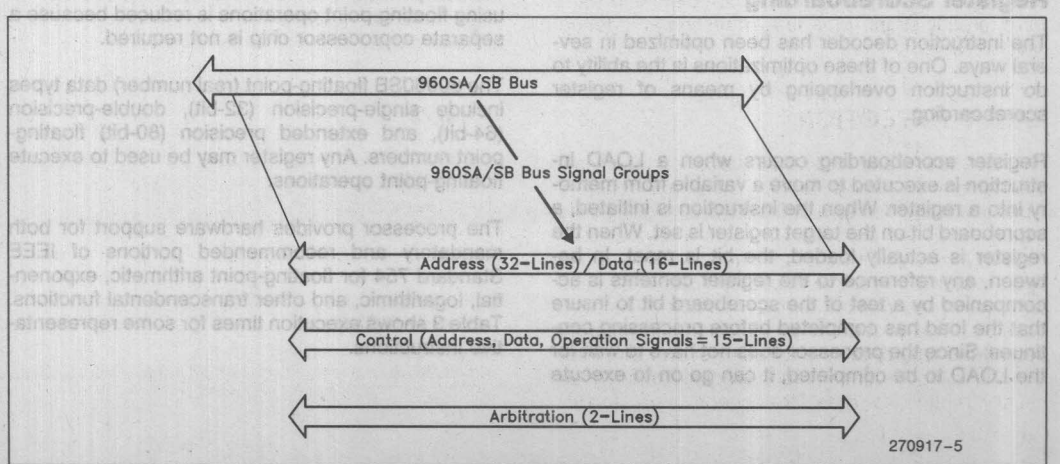


Figure 5. 80960SA and 80960SB Bus Signal Groups

Debug Features

The 80960SA and 80960SB have built-in debug capabilities. There are two types of breakpoints and six different trace modes. The debug features are controlled by two internal 32-bit registers, the Process-Controls Word and the Trace-Controls Word. By setting bits in these control words, a software debug monitor can closely control how the processor responds during program execution.

The 80960SA and 80960SB have both hardware and software breakpoints. They provide two hardware breakpoint registers on-chip which can be set by a special command to any value. When the instruction pointer matches the value in one of the breakpoint registers, the breakpoint will fire, and a breakpoint handling routine is called automatically.

Tracing is available for all instructions (single-step execution), calls and returns, and branching. Each different type of trace may be enabled separately by a special debug instruction. In each case, the 80960SA and 80960SB execute the instruction first and then call a trace handling routine (usually part of a software debug monitor). Further program execution is halted until the trace routine is completed. When the trace event handling routine is completed, instruction execution resumes at the next instruction. The 80960SA and 80960SB's tracing mechanisms, which are implemented completely in hardware, greatly simplify the task of testing and debugging software.

FAULT DETECTION

The 80960SA and 80960SB have an automatic mechanism to handle faults. There are ten fault types including trace, arithmetic, and floating-point faults. When the processor detects a fault, it automatically calls the appropriate fault handling routine and saves the current instruction pointer and necessary state information to make efficient recovery possible. The processor posts diagnostic information on the type of fault to a Fault Record. Like interrupt handling routines, fault handing routines are usually written to meet the needs of a specific application and are often included as part of the operating system or kernel.

For each of the ten fault types, there are numerous subtypes that provide specific information about a fault. For example, a floating-point fault may have its subtype set to an Overflow or Zero-Divide fault. The fault handler can use this specific information to respond correctly to the fault.

BUILT-IN TESTABILITY

Upon reset, the 80960SA and 80960SB automatically conducts an extensive internal test (self-test) of its major blocks of logic. Then, before executing its first instruction, it does a zero check sum on the first eight words in memory to ensure that the system has been loaded correctly. If a problem is discovered at any point during the self-test, the 80960SA and 80960SB will indicate a failure and will not begin program execution. The self-test takes approximately 47,000 cycles to complete.

System manufacturers can use the 80960SA and 80960SB's self-test feature during incoming parts inspection. No special diagnostic programs need to be written, and the test is both thorough and fast. The self-test capability helps ensure that defective parts will be discovered before systems are shipped, and once in the field, the self-test makes it easier to distinguish between problems caused by processor failure and problems resulting from other causes.

CHMOS

The 80960SA and 80960SB are fabricated using Intel's CHMOS IV (Complementary High Speed Metal Oxide Semiconductor) process. This advanced technology eliminates the frequency and reliability limitations of older CMOS processes and opens a new era in microprocessor performance. It combines the high performance capabilities of Intel's industry-leading HMOS technology with the high density and low power characteristics of CMOS. The 80960SA and 80960SB are available at 10 MHz and 16 MHz.

Table 4. 80960SA and 80960SB Pin Description: Bus Signals

Symbol	Type	Name and Function
CLK2	I	**SYSTEM CLOCK** provides the fundamental timing for 80960SA and 80960SB systems. CLK2 is divided by two inside the 80960SA and 80960SB to generate the internal processor clock.
A31–A16	O T.S.	**ADDRESS BUS** carries the upper 16 bits of the 32-bit address to memory. It is valid throughout the burst cycle, no latch is required.
AD15–AD1, D0	I/O T.S.	**ADDRESS/DATA BUS** carries the low order 32-bit addresses and 16-bit data to and from memory. AD15–AD4 must be latched since the cycle following the address cycle carries data on the bus.
A3–A1	O T.S.	**ADDRESS BUS** carries the byte addresses of the 32-bit address to memory. These three bits are incremented during a burst access indicating the next byte address of the burst access. Note that A3–A1 are duplicated with AD3–AD1 during the address cycle.
ALE	O T.S.	**ADDRESS LATCH ENABLE** indicates the transfer of a physical address. ALE is asserted during a Ta cycle and deasserted before the beginning of the following Td state. It is active high and floats to a high impedance state during a hold cycle (Th or Thr).
$\overline{AS}$	O T.S.	**ADDRESS STATUS** indicates an address state. $\overline{AS}$ is asserted every Ta state and deasserted during the following Td state. $\overline{AS}$ is driven HIGH during reset.
W/$\overline{R}$	O T.S.	**WRITE/READ** specifies, during a Ta cycle, whether the operation is write or read. It is latched on-chip and remains valid during Td cycles.
$\overline{DEN}$	O T.S.	**DATA ENABLE** is asserted during Td cycles and indicates transfer of data on the AD lines. The AD lines should not be driven by an external source unless $\overline{DEN}$ is asserted. When $\overline{DEN}$ is asserted, the outputs from the previous cycle are guaranteed to be tri-stated. In addition, $\overline{DEN}$ deasserted indicates inputs have been captured and therefore input hold times can be disregarded. $\overline{DEN}$ is driven to a HIGH during reset.
READY	I	**READY** indicates that data on AD lines can be sampled or removed. If $\overline{READY}$ is not asserted during a Td cycle the Td cycle is extended to the next cycle by inserting a wait state (Tw).
DT/$\overline{R}$	O T.S.	**DATA TRANSMIT/RECEIVE** indicates the direction of the data transfer to and from the bus. It is low during Ta and Td cycles for a read or interrupt acknowledgement; it is high during Ta and Td cycles for a write. DT/$\overline{R}$ never changes state when $\overline{DEN}$ is asserted. DT/$\overline{R}$ is driven HIGH during reset.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = Tri-State.

Table 4. 80960SA and 80960SB Pin Description: Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{BLAST}/\overline{FAIL}$	O T.S.	**BURST LAST** indicates the last data cycle (Td) of a burst access. It is asserted low during the last Td and associated Tw cycles in a burst access. **INITIALIZATION FAILURE** indicates that the processor has failed to initialize correctly. The failure state is indicated by a combination of $\overline{BLAST}$ asserted and both $\overline{BE}$ signals not asserted. This condition occurs after $\overline{RESET}$ is deasserted and before the first bus transaction begins. $\overline{FAIL}$ is asserted while the processor performs a self-test. If the self-test completes successfully, then $\overline{FAIL}$ is deasserted. Next, the processor performs a zero checksum on the first eight words of memory. If it fails, $\overline{FAIL}$ is asserted for a second time and remains asserted; if it passes, system initialization continues and $\overline{FAIL}$ remains deasserted.
$\overline{RESET}$	I	**RESET** clears the internal logic of the processor and causes it to reinitialize. During $\overline{RESET}$ assertion, the input pins are ignored (except for $\overline{INT0}$, $\overline{INT1}$, $\overline{INT3}$, $\overline{LOCK}$), the tri-state output pins are placed in a HIGH impedance state (except for DT/$\overline{R}$, $\overline{DEN}$, and $\overline{AS}$), and other output pins are placed in their non-asserted state. $\overline{RESET}$ must be asserted for at least 41 CLK2 cycles for a predictable reset. Optionally, for a synchronous reset, the LOW to HIGH transition of $\overline{RESET}$ should occur after the rising edge of both CLK2 and the external bus clock, and before the next rising edge of CLK2. The interrupt pins indicate the initializtion sequence executed. Typical initialization requires driving only $\overline{INT0}$ and $\overline{INT3}$ to a HIGH state. The reset conditions follow:

$\overline{INT0}$	INT1	$\overline{INT3}$	$\overline{LOCK}$	Action Taken
1	x	1	1	Run self-test (core initialization)
0	0	1	1	Disable self-test
0	1	x	x	Reserved
x	x	0	x	Reserved
x	x	x	0	ONCE mode (see LOCK pin)

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = Tri-State.

6

Table 4. 80960SA and 80960SB Pin Description: Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{BE1}$–$\overline{BE0}$	O T.S.	**BYTE ENABLE LINES** specify which data bytes (up to two) on the bus take part in the current bus cycle. $\overline{BE1}$ corresponds to AD15–AD8 and $\overline{BE0}$ corresponds to AD7–AD1, D0. The byte enable lines are asserted appropriately during each data cycle. **INITIALIZATION FAILURE** indicates that the processor has failed to initialize correctly. The failure state is indicated by a combination of $\overline{BLAST}$ asserted and both $\overline{BE}$ signals not asserted. This condition occurs after $\overline{RESET}$ is deasserted and before the first bus transaction begins. $\overline{FAIL}$ is asserted while the processor performs a self-test. If the self-test completes successfully, then $\overline{FAIL}$ is deasserted. Next, the processor performs a zero checksum on the first eight words of memory. If it fails, $\overline{FAIL}$ is asserted for a second time and remains asserted; if it passes, system initialization continues and $\overline{FAIL}$ remains deasserted.
$\overline{INT0}$	I	**INTERRUPT 0** indicates a pending interrupt. The bus interrupt control register determines in which way the signal should be interpreted. To signal an interrupt request in a synchronous system, this pin (as well as the other interrupt pins) must be enabled by being deasserted for at least one bus cycle and then asserted for at least one additional bus cycle; in an asynchronous system, the pin must remain deasserted for at least two bus cycles and then be asserted for at least two more bus cycles. $\overline{INT0}$ is sampled during RESET to determine if the self-test sequence is to be executed.
INT1	I	**INTERRUPT 1** indicates a direct interrupt, like $\overline{INT0}$. INT1 is sampled during RESET to determine if the self-test sequence is to be executed.
INT2/INTR	I	**INTERRUPT 2/INTERRUPT REQUEST:** The interrupt control register determines how this pin is interpreted. If INT2, it has the same interpretation as the $\overline{INT0}$ and INT1 pins. If INTR, it is used to receive an interrupt request from an external 8259A compatible interrupt controller.
$\overline{INT3}$/$\overline{INTA}$	I/O T.S.	**INTERRUPT 3/INTERRUPT ACKNOWLEDGE:** The interrupt control register determines how this pin is interpreted. If $\overline{INT3}$, it has the same interpretation as the $\overline{INT0}$ and INT1 pins. If INTA, it is used as an output to control interrupt-acknowledge bus transactions. The INTA output is latched on-chip and remains valid during Td cycles. $\overline{INT3}$ must be pulled to a HIGH state during RESET.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = Tri-State.

Table 4. 80960SA and 80960SB Pin Description: Bus Signals (Continued)

Symbol	Type	Name and Function
$\overline{LOCK}$	I/O O.D.	**BUS LOCK** prevents other bus masters from gaining control of the bus following the current cycle (if they would assert $\overline{LOCK}$ to do so). $\overline{LOCK}$ is used by the processor or any bus agent when it performs indivisible Read/Modify/Write (RMW) operations. Do not leave $\overline{LOCK}$ unconnected. It must be pulled HIGH for the processor to function properly. For a read that is designated as an RMW-read, $\overline{LOCK}$ is examined. If asserted, the processor waits until it is not asserted; if not asserted, the processor asserts $\overline{LOCK}$ during the Ta cycle and leaves it asserted. A write that is designated as an RMW-write deasserts $\overline{LOCK}$ in the Ta cycle. During the time $\overline{LOCK}$ is asserted, a bus agent can perform a normal read or write but no RMW operations. $\overline{LOCK}$ is also held asserted during an interrupt-acknowledge transaction. **ONCE MODE:** The $\overline{LOCK}$ pin is sampled during reset. If it is asserted LOW at the end of RESET, all outputs will be tristated until the part is reset. ONCE MODE is used in conjunction with an ICE.
HOLD	I	**HOLD:** HOLD indicates a request from a secondary bus master to acquire the bus. When the processor receives HOLD and grants another master control of the bus, it floats its tri-state bus lines and then asserts HLDA and enters the Th state. When HOLD is deasserted, the processor will deassert HLDA and go to either the Ti or Ta state.
HLDA	O T.S.	**HOLD ACKNOWLEDGE:** HLDA indicates that bus control has been relinquished to another bus master. This signal is always driven. At RESET it is driven LOW.
N.C.	N/A	**NOT CONNECTED** indicates pins should not be connected. Never connect any pin marked N.C.

I/O = Input/Output, O = Output, I = Input, O.D. = Open-Drain, T.S. = Tri-State.

ELECTRICAL SPECIFICATIONS

Power and Grounding

The 80960SA and 80960SB are implemented in CHMOS IV technology and have modest power requirements. Their high clock frequency and numerous output buffers (address/data, control, error, and arbitration signals) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 12 V_{CC} and 13 V_{SS} pins separately feed functional units of the 80960SA and 80960SB in the package.

Power and ground connections must be made to all power and ground pins of the 80960SA and 80960SB. On the circuit board, all V_{CC} pins must be strapped closely together, preferably on a power plane. Likewise, all V_{SS} pins should be strapped together, preferably on a ground plane. These pins may not be connected together within the chip.

Power Decoupling Recommendations

Liberal decoupling capacitance should be placed near the 80960SA and 80960SB. The processor can cause transient power surges when driving the bus, particularly when it is connected to a large capacitive load.

Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening the board traces between the processor and decoupling capacitors as much as possible.

6

drive network, which assumes that the circuit board has a characteristic impedance of 100Ω. The advantage of terminating the output signals in this fashion is that it limits signal swing and reduces A.C. power consumption.

Characteristic Curves

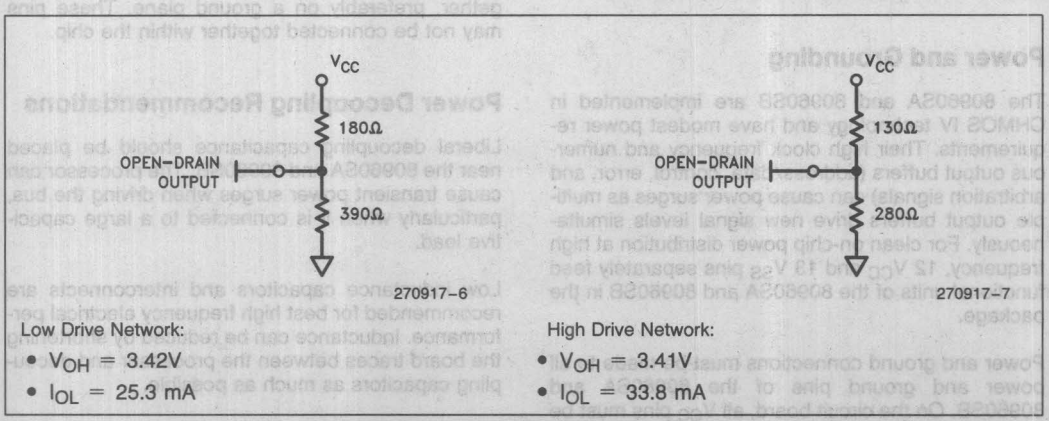
The 80960SA and 80960SB characteristic curves shown in Figures 7 through 10 supply information regarding typical supply currents, typical current versus frequency, worst case voltage versus output current on open drain pins, and capacitive derating curves.

Figure 7 shows the typical supply current requirements over the operating temperture range of the

Test Load Circuit

Figure 11 illustrates load circuit used to test the 80960SA and 80960SB's tristate pins, and Figure 12 shows the load circuit used to test the open drain outputs. The open drain test uses an active load circuit in the form of a matched diode bridge. Since the open-drain output sinks current, only the I_{OL} legs of the bridge are necessary and the I_{OH} legs are not used. When the 80960SA and 80960SB driver under test is turned off, the output pin in pulled up to V_{REF} (i.e., V_{OH}). Diode D1 is turned off and the I_{OL} current source flow through diode D2.

When the 80960SA and 80960SB open-drain driver under test is on, diode D1 is also on, and the voltage on the pin begin tested drops to V_{OL}. Diode D2 turns off and I_{OL} flows through diode D1.



Low Drive Network:

- V_{OH} = 3.42V
- I_{OL} = 25.3 mA

High Drive Network:

- V_{OH} = 3.41V
- I_{OL} = 33.8 mA

Figure 6. Open Drain Connection Recommendations for Low and High Current Drive Networks for the $\overline{\text{LOCK}}$ Pin

NOT AVAILABLE

Figure 7. Typical Supply Current (I_{CC})

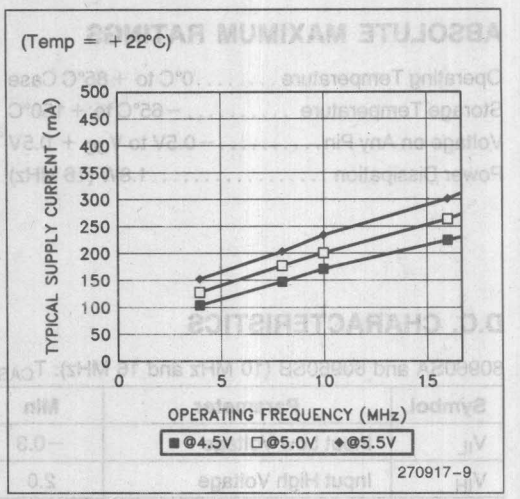


Figure 8. Typical Current vs Frequency

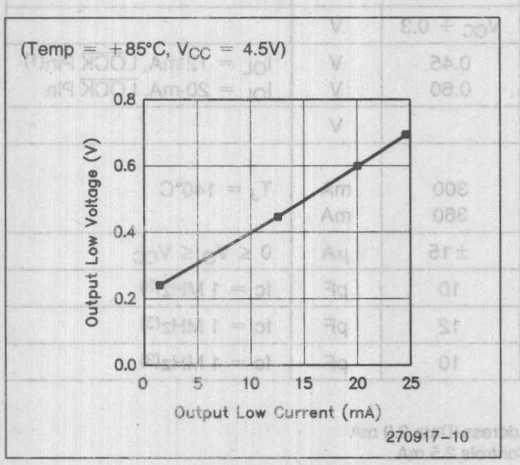


Figure 9. Worst Case Voltage vs Output Current on Open-Drain Pins

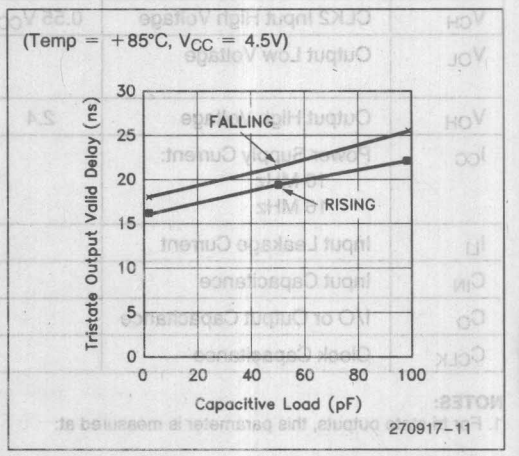


Figure 10. Capacitive Derating Curve

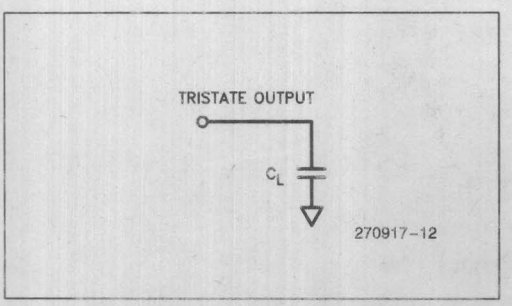


Figure 11. Test Load Circuit for Tri-State Output Pins

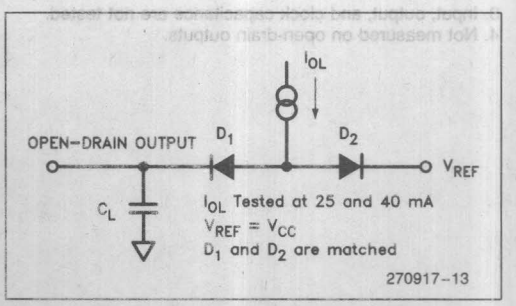


Figure 12. Test Load Circuit for Open-Drain Output Pins

6

ABSOLUTE MAXIMUM RATINGS

Operating Temperature . . . . . 0°C to +85°C Case
Storage Temperature . . . . . −65°C to +150°C
Voltage on Any Pin . . . . . −0.5V to V_{CC} + 0.5V
Power Dissipation . . . . . 1.8W (16 MHz)

NOTICE: This data sheet contains information on products in the sampling and initial production phases of development. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

D.C. CHARACTERISTICS

80960SA and 80960SB (10 MHz and 16 MHz): T_{CASE} = 0°C to +85°C, V_{CC} = 5V ±10%.

Symbol	Parameter	Min	Max	Units	Conditions
V_{IL}	Input Low Voltage	−0.3	+0.8	V	
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{CL}	CLK2 Input Low Voltage	−0.3	+0.8	V	
V_{CH}	CLK2 Input High Voltage	0.55 V_{CC}	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage		0.45 0.60	V V	I_{OL} = 12 mA, $\overline{LOCK}$ Pin(1) I_{OL} = 20 mA, $\overline{LOCK}$ Pin
V_{OH}	Output High Voltage	2.4		V	
I_{CC}	Power Supply Current: 10 MHz 16 MHz		 300 360	 mA mA	 T_J = 140°C
I_{LI}	Input Leakage Current		±15	μA	0 ≤ V_O ≤ V_{CC}
C_{IN}	Input Capacitance		10	pF	fc = 1 MHz(3)
C_O	I/O or Output Capacitance		12	pF	fc = 1 MHz(3)
C_{CLK}	Clock Capacitance		10	pF	fc = 1 MHz(3)

NOTES:
1. For tri-state outputs, this parameter is measured at:
   Address/Data 2.0 mA
   Controls 2.5 mA
2. This parameter is measured at:
   Address/Data −0.5 mA
   Controls −0.45 mA
   ALE −2.5 mA
3. Input, output, and clock capacitance are not tested.
4. Not measured on open-drain outputs.

A.C. SPECIFICATIONS

This section describes the A.C. specifications for the 80960SA and 80960SB pins. All input and output timings are specified relative to the 1.5V level of the rising edge of CLK2, and refer to the time at which the signal reaches (for output delay and input setup) or leaves (for hold time) the level of LOW (0.8V) or HIGH (2.0V). All A.C. testing should be done with input voltages of 0.4V and 2.4V, except for the clock (CLK2), which should be tested with input voltages of 0.45V and 0.55V V_{CC}. See Figure 13 for timing relationships for the 80960SA and 80960SB signals.

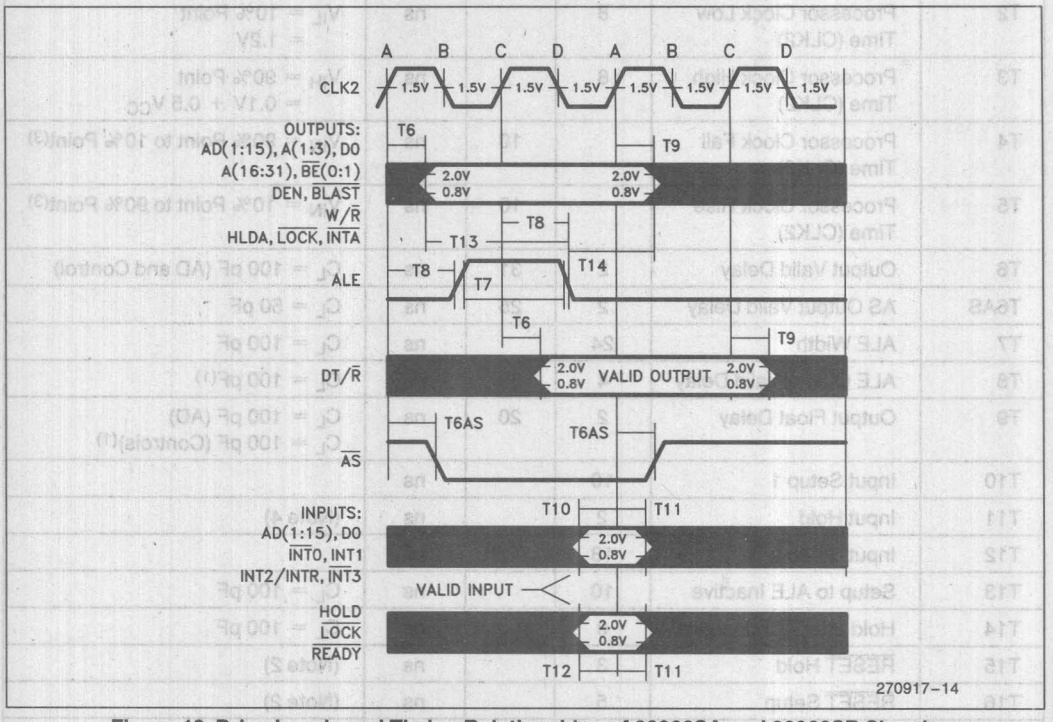


Figure 13. Drive Levels and Timing Relationships of 80960SA and 80960SB Signals

A.C. Specification Tables

80960SA and 80960SB A.C. Characteristics (10 MHz)

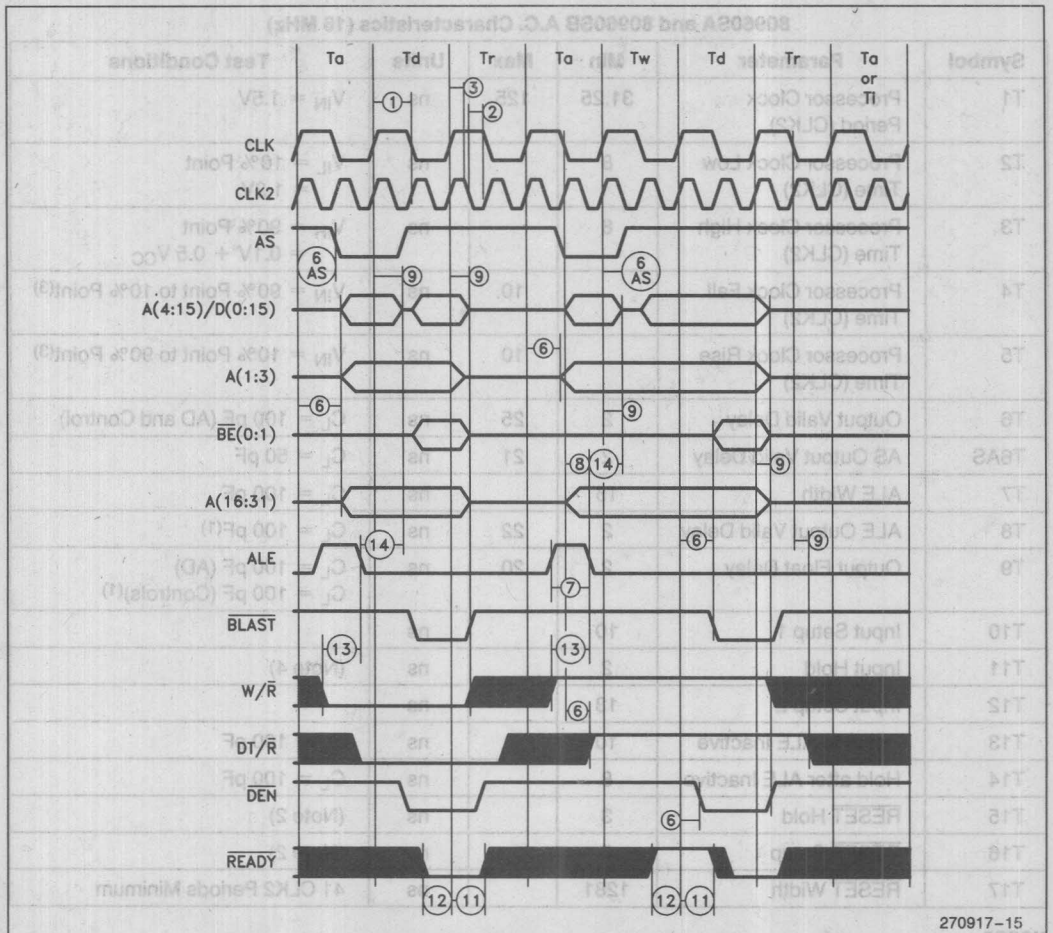
Symbol	Parameter	Min	Max	Units	Test Conditions
T1	Processor Clock Period (CLK2)	50	125	ns	V_{IN} = 1.5V
T2	Processor Clock Low Time (CLK2)	8		ns	V_{IL} = 10% Point = 1.2V
T3	Processor Clock High Time (CLK2)	8		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point(3)
T5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point(3)
T6	Output Valid Delay	2	31	ns	C_L = 100 pF (AD and Control)
T6AS	AS Output Valid Delay	2	25	ns	C_L = 50 pF
T7	ALE Width	24		ns	C_L = 100 pF
T8	ALE Output Valid Delay	4	33	ns	C_L = 100 pF(1)
T9	Output Float Delay	2	20	ns	C_L = 100 pF (AD) C_L = 100 pF (Controls)(1)
T10	Input Setup 1	10		ns	
T11	Input Hold	2		ns	(Note 4)
T12	Input Setup 2	13		ns	
T13	Setup to ALE Inactive	10		ns	C_L = 100 pF
T14	Hold after ALE Inactive	8		ns	C_L = 100 pF
T15	$\overline{\text{RESET}}$ Hold	3		ns	(Note 2)
T16	$\overline{\text{RESET}}$ Setup	5		ns	(Note 2)
T17	$\overline{\text{RESET}}$ Width	2050		ns	41 CLK2 Periods Minimum

NOTES:
1. A float condition occurs when the maximum output current becomes less than ILO. Float delay is not tested, but should be no longer than the valid delay.
2. Meeting $\overline{\text{RESET}}$ setup and hold times is an optional method of synchronizing your clocks. If you decide to use an asynchronous reset, then synchronizing the clock can be accomplished by using $\overline{\text{AS}}$.
3. Processor clock (CLK2) rise time and fall time are not tested.
4. ICE requires a minimum of 4 ns input hold time.

80960SA and 80960SB A.C. Characteristics (16 MHz)

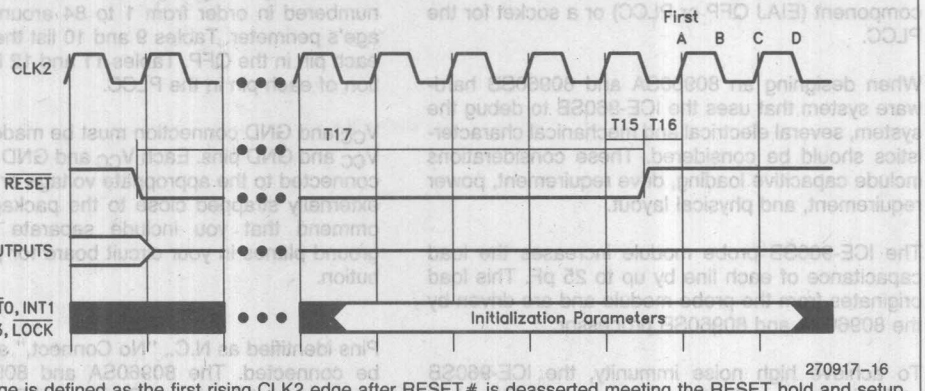
Symbol	Parameter	Min	Max	Units	Test Conditions
T1	Processor Clock Period (CLK2)	31.25	125	ns	V_{IN} = 1.5V
T2	Processor Clock Low Time (CLK2)	8		ns	V_{IL} = 10% Point = 1.2V
T3	Processor Clock High Time (CLK2)	8		ns	V_{IH} = 90% Point = 0.1V + 0.5 V_{CC}
T4	Processor Clock Fall Time (CLK2)		10	ns	V_{IN} = 90% Point to 10% Point(3)
T5	Processor Clock Rise Time (CLK2)		10	ns	V_{IN} = 10% Point to 90% Point(3)
T6	Output Valid Delay	2	25	ns	C_L = 100 pF (AD and Control)
T6AS	AS Output Valid Delay	2	21	ns	C_L = 50 pF
T7	ALE Width	15		ns	C_L = 100 pF
T8	ALE Output Valid Delay	2	22	ns	C_L = 100 pF(1)
T9	Output Float Delay	2	20	ns	C_L = 100 pF (AD) C_L = 100 pF (Controls)(1)
T10	Input Setup 1	10		ns	
T11	Input Hold	2		ns	(Note 4)
T12	Input Setup 2	13		ns	
T13	Setup to ALE Inactive	10		ns	C_L = 100 pF
T14	Hold after ALE Inactive	8		ns	C_L = 100 pF
T15	$\overline{\text{RESET}}$ Hold	3		ns	(Note 2)
T16	$\overline{\text{RESET}}$ Setup	5		ns	(Note 2)
T17	$\overline{\text{RESET}}$ Width	1281		ns	41 CLK2 Periods Minimum

NOTES:
1. A float condition occurs when the maximum output current becomes less than ILO. Float delay is not tested, but should be no longer than the valid delay.
2. Meeting $\overline{\text{RESET}}$ setup and hold times is an optional method of synchronizing your clocks. If you decide to use an asynchronous reset, then synchronizing the clock can be accomplished by using $\overline{\text{AS}}$.
3. Processor clock (CLK2) rise time and fall time are not tested.
4. ICE requires a minimum of 4 ns input hold time.



NOTES:
1. The AD and control signals are driven at all times except during a HOLD acknowledge (HLDA asserted) RESET, and ONCE mode.
2. The AD and control signals may toggle during idle (Ti) or recovery (Tr) cycles.

Figure 14. Timing Relationships of the 80960SA and 80960SB Bus



1. The A edge is defined as the first rising CLK2 edge after RESET# is deasserted meeting the RESET hold and setup times.
2. Initialization Parameters must be setup at least four CLK2s prior to the first A edge.

Figure 15. RESET Signal Timing

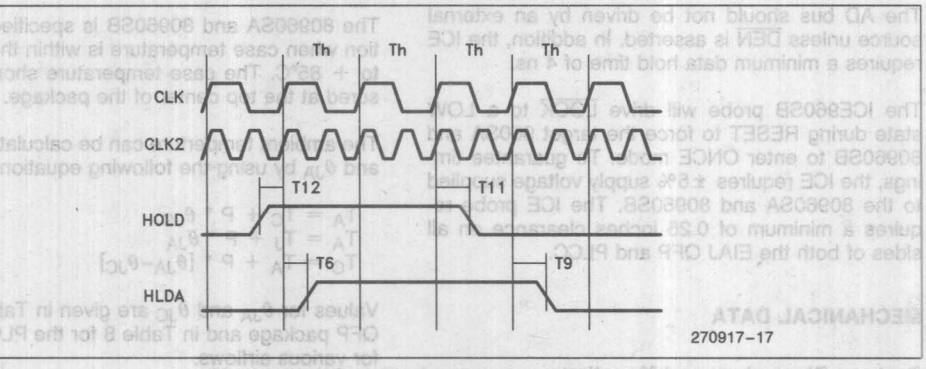


Figure 16. HOLD Timing Relationships

Design Considerations

Input hold times can be disregarded by the designer whenever the input is removed because a subsequent output from the processor is deasserted (e.g., $\overline{DEN}$ becomes deasserted).

Whenever the processor generates an output that indicates a transition into a subsequent state, any outputs that are specified to be tri-stated in this new state are guaranteed to be tri-stated. For example, in the Td cycle following a Ta cycle for a read, the minimum output delay of $\overline{DEN}$ is 2 ns, but the maximum float time of AD is 20 ns. When $\overline{DEN}$ is asserted, however, the AD outputs are guaranteed to have been tri-stated.

Designing for the ICE-960SB

The 80960SA and 80960SB In-Circuit Emulator assists in debugging 80960SA and 80960SB hardware and software designs. The product consists of a probe module, cable, control unit, and power supply. Because of the high operating frequency of the 80960SA and 80960SB systems, the probe module

6

connects directly to the 80960SA and 80960SB component (EIAJ QFP or PLCC) or a socket for the PLCC.

When designing an 80960SA and 80960SB hardware system that uses the ICE-960SB to debug the system, several electrical and mechanical characteristics should be considered. These considerations include capacitive loading, drive requirement, power requirement, and physical layout.

The ICE-960SB probe module increases the load capacitance of each line by up to 25 pF. This load originates from the probe module and are driven by the 80960SA and 80960SB processor.

To achieve high noise immunity, the ICE-960SB probe is powered by the user's system. The high-speed probe circuitry draws up to 1.1A plus the maximum current (I_{CC}) of the 80960SA and 80960SB processor.

The AD bus should not be driven by an external source unless $\overline{DEN}$ is asserted. In addition, the ICE requires a minimum data hold time of 4 ns.

The ICE960SB probe will drive $\overline{LOCK}$ to a LOW state during RESET to force the target 960SA and 80960SB to enter ONCE mode. To guarantee timings, the ICE requires ±5% supply voltage supplied to the 80960SA and 80960SB. The ICE probe requires a minimum of 0.25 inches clearance on all sides of both the EIAJ QFP and PLCC.

MECHANICAL DATA

Package Dimensions and Mounting

The 80960SA and 80960SB is available in two different packages: an 80-lead quad flat pack (EIAJ QFP), shown in Figure 17, and an 84-lead plastic leaded chip carrier (PLCC), shown in Figure 18.

Pin Assignment

The QFP and PLCC have different pin assignments. The QPF pins are numbered in order from 1 to 80 around the package's perimeter. The PLCC pins are numbered in order from 1 to 84 around the package's perimeter. Tables 9 and 10 list the function of each pin in the QFP. Tables 11 and 12 list the function of each pin in the PLCC.

V_{CC} and GND connection must be made to multiple V_{CC} and GND pins. Each V_{CC} and GND pin must be connected to the appropriate voltage or ground and externally strapped close to the package. We recommend that you include separate power and ground planes in your circuit board for power distribution.

NOTE:
Pins identified as N.C., "No Connect," should never be connected. The 80960SA and 80960SB QFP package contains two N.C. pins and PLCC package contains six N.C. pins.

Package Thermal Specification

The 80960SA and 80960SB is specified for operation when case temperature is within the range 0°C to + 85°C. The case temperature should be measured at the top center of the package.

The ambient temperture can be calculated from θ_{JC} and θ_{JA} by using the following equations:

$$T_A = T_C + P * \theta_{JC}$$
$$T_A = T_J + P * \theta_{JA}$$
$$T_C = T_A + P * [\theta_{JA} - \theta_{JC}]$$

Values for θ_{JA} and θ_{JC} are given in Table 7 for the QFP package and in Table 8 for the PLCC package for various airflows.

WAVEFORMS

Figure 19 through 22 shows the waveforms for various signals on the 80960SA and 80960SB's bus.

Table 7. QFP Package, Thermal Resistance—°C/Watt

Parameter	Airflow—ft/min (m/sec)						
	0	50	100	200	400	600	800
θ_{JA} Junction to Ambient (Case measured in the middle of the top of the package) (No Heatsink)	52.0	na	na	46.0	35.0	na	na
θ_{JC} Junction to Case	4.0	na	na	4.5	5.5	na	na

NOTES:
1. This table applies to an 80960SA and 80960SB QFP soldered directly onto a board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.

Table 8. PLCC Package, Thermal Resistance—°C/Watt

Parameter	Airflow—ft/min (m/sec)						
	0	50	100	200	400	600	800
θ_{JA} Junction to Ambient (No Heatsink)	33	na	na	na	na	na	na
θ_{JC} Junction to Case	11	na	na	na	na	na	na

NOTES:
1. This table applies to an 80960SA and 80960SB PLCC soldered directly onto a board.
2. $\theta_{JA} = \theta_{JC} + \theta_{CA}$.

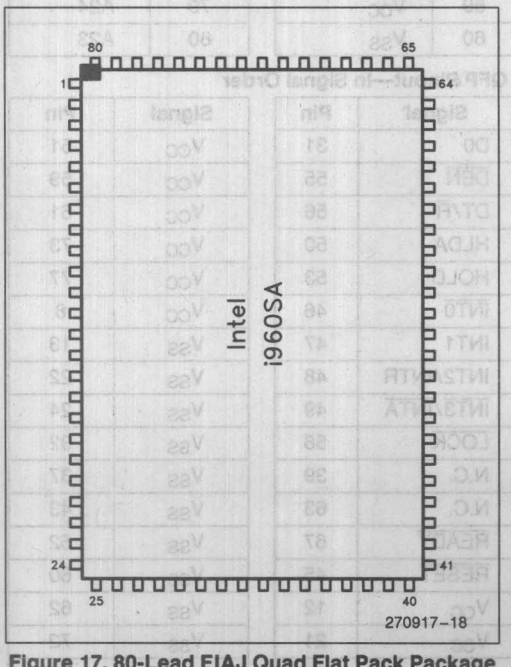


Figure 17. 80-Lead EIAJ Quad Flat Pack Package

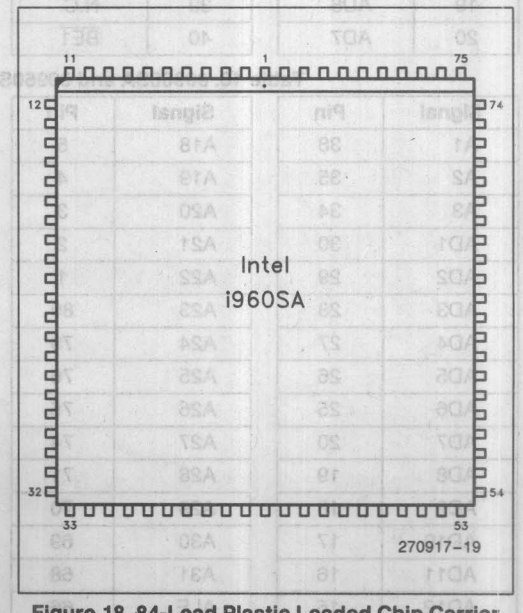


Figure 18. 84-Lead Plastic Leaded Chip Carrier

6

Table 9. 80960SA and 80960SB QFP Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
1	A22	21	V_{CC}	41	$\overline{BE0}$	61	V_{CC}
2	A21	22	V_{SS}	42	V_{CC}	62	V_{SS}
3	A20	23	V_{CC}	43	V_{SS}	63	N.C.
4	A19	24	V_{SS}	44	CLK2	64	$\overline{AS}$
5	A18	25	AD6	45	$\overline{RESET}$	65	V_{SS}
6	A17	26	AD5	46	$\overline{INT0}$	66	ALE
7	A16	27	AD4	47	INT1	67	$\overline{READY}$
8	V_{CC}	28	AD3	48	INT2/INTR	68	A31
9	V_{SS}	29	AD2	49	$\overline{INT3}/\overline{INTA}$	69	A30
10	AD15	30	AD1	50	HLDA	70	A29
11	AD14	31	AD0	51	V_{CC}	71	A28
12	V_{CC}	32	V_{SS}	52	V_{SS}	72	V_{SS}
13	V_{SS}	33	V_{CC}	53	HOLD	73	V_{CC}
14	AD13	34	A3	54	W/$\overline{R}$	74	A27
15	AD12	35	A2	55	$\overline{DEN}$	75	A26
16	AD11	36	V_{CC}	56	DT/$\overline{R}$	76	A25
17	AD10	37	V_{SS}	57	$\overline{BLAST}$	77	V_{CC}
18	AD9	28	A1	58	$\overline{LOCK}$	78	V_{SS}
19	AD8	39	N.C.	59	V_{CC}	79	A24
20	AD7	40	$\overline{BE1}$	60	V_{SS}	80	A23

Table 10. 80960SA and 80960SB QFP Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
A1	38	A18	5	D0	31	V_{CC}	51
A2	35	A19	4	$\overline{DEN}$	55	V_{CC}	59
A3	34	A20	3	DT/$\overline{R}$	56	V_{CC}	61
AD1	30	A21	2	HLDA	50	V_{CC}	73
AD2	29	A22	1	HOLD	53	V_{CC}	77
AD3	28	A23	80	$\overline{INT0}$	46	V_{CC}	8
AD4	27	A24	79	INT1	47	V_{SS}	13
AD5	26	A25	76	INT2/INTR	48	V_{SS}	22
AD6	25	A26	75	$\overline{INT3}/\overline{INTA}$	49	V_{SS}	24
AD7	20	A27	74	$\overline{LOCK}$	58	V_{SS}	32
AD8	19	A28	71	N.C.	39	V_{SS}	37
AD9	18	A29	70	N.C.	63	V_{SS}	43
AD10	17	A30	69	$\overline{READY}$	67	V_{SS}	52
AD11	16	A31	68	$\overline{RESET}$	45	V_{SS}	60
AD12	15	ALE	66	V_{CC}	12	V_{SS}	62
AD13	14	$\overline{AS}$	64	V_{CC}	21	V_{SS}	72
AD14	11	$\overline{BE0}$	41	V_{CC}	23	V_{SS}	78
AD15	10	$\overline{BE1}$	40	V_{CC}	33	V_{SS}	9
A16	7	$\overline{BLAST}$	57	V_{CC}	36	V_{SS}	65
A17	6	CLK2	44	V_{CC}	42	W/$\overline{R}$	54

Table 11. 80960SA and 80960SB PLCC Pinout—In Pin Order

Pin	Signal	Pin	Signal	Pin	Signal	Pin	Signal
1	V_{CC}	22	V_{SS}	43	V_{SS}	64	HOLD
2	N.C.	23	N.C.	44	V_{CC}	65	N.C.
3	A27	24	AD13	45	A3	66	W/$\overline{R}$
4	A26	25	AD12	46	A2	67	$\overline{DEN}$
5	A25	26	AD11	47	V_{CC}	68	DT/$\overline{R}$
6	V_{CC}	27	AD10	48	V_{SS}	69	$\overline{BLAST}$
7	V_{SS}	28	AD9	49	A1	70	$\overline{LOCK}$
8	A24	29	AD8	50	N.C.	71	V_{CC}
9	A23	30	AD7	51	$\overline{BE1}$	72	V_{SS}
10	A22	31	V_{CC}	52	$\overline{BE0}$	73	V_{CC}
11	A21	32	V_{SS}	53	V_{CC}	74	V_{SS}
12	A20	33	V_{CC}	54	V_{SS}	75	N.C.
13	A19	34	V_{SS}	55	CLK2	76	$\overline{AS}$
14	A18	35	AD6	56	$\overline{RESET}$	77	V_{SS}
15	A17	36	AD5	57	$\overline{INT0}$	78	ALE
16	A16	37	AD4	58	$\overline{INT1}$	79	$\overline{READY}$
17	V_{CC}	38	AD3	59	INT2/INTR	80	A31
18	V_{SS}	39	AD2	60	$\overline{INT3}$/$\overline{INTA}$	81	A30
19	AD15	40	AD1	61	HLDA	82	A29
20	AD14	41	D0	62	V_{CC}	83	A28
21	V_{CC}	42	N.C.	63	V_{SS}	84	V_{SS}

6

Table 12. 80960SA and 80960SB PLCC Pinout—In Signal Order

Signal	Pin	Signal	Pin	Signal	Pin	Signal	Pin
A1	49	A18	14	DT/$\overline{R}$	68	V_{CC}	44
A2	46	A19	13	HLDA	61	V_{CC}	47
A3	45	A20	12	HOLD	64	V_{CC}	53
D0	41	A21	11	$\overline{INT0}$	57	V_{CC}	6
AD1	40	A22	10	INT1	58	V_{CC}	62
AD2	39	A23	9	INT2/INTR	59	V_{CC}	71
AD3	38	A24	8	$\overline{INT3}$/$\overline{INTA}$	60	V_{CC}	73
AD4	37	A25	5	LOCK	70	V_{SS}	18
AD5	36	A26	4	N.C.	2	V_{SS}	22
AD6	35	A27	3	N.C.	23	V_{SS}	32
AD7	30	A28	83	N.C.	42	V_{SS}	34
AD8	29	A29	82	N.C.	50	V_{SS}	43
AD9	28	A30	81	N.C.	65	V_{SS}	48
AD10	27	A31	80	N.C.	75	V_{SS}	54
AD11	26	ALE	78	$\overline{READY}$	79	V_{SS}	63
AD12	25	$\overline{AS}$	76	$\overline{RESET}$	56	V_{SS}	7
AD13	24	$\overline{BE0}$	52	V_{CC}	1	V_{SS}	72
AD14	20	$\overline{BE1}$	51	V_{CC}	17	V_{SS}	74
AD15	19	$\overline{BLAST}$	69	V_{CC}	21	V_{SS}	77
AD16	16	CLK2	55	V_{CC}	31	V_{SS}	84
A17	15	$\overline{DEN}$	67	V_{CC}	33	W/$\overline{R}$	66

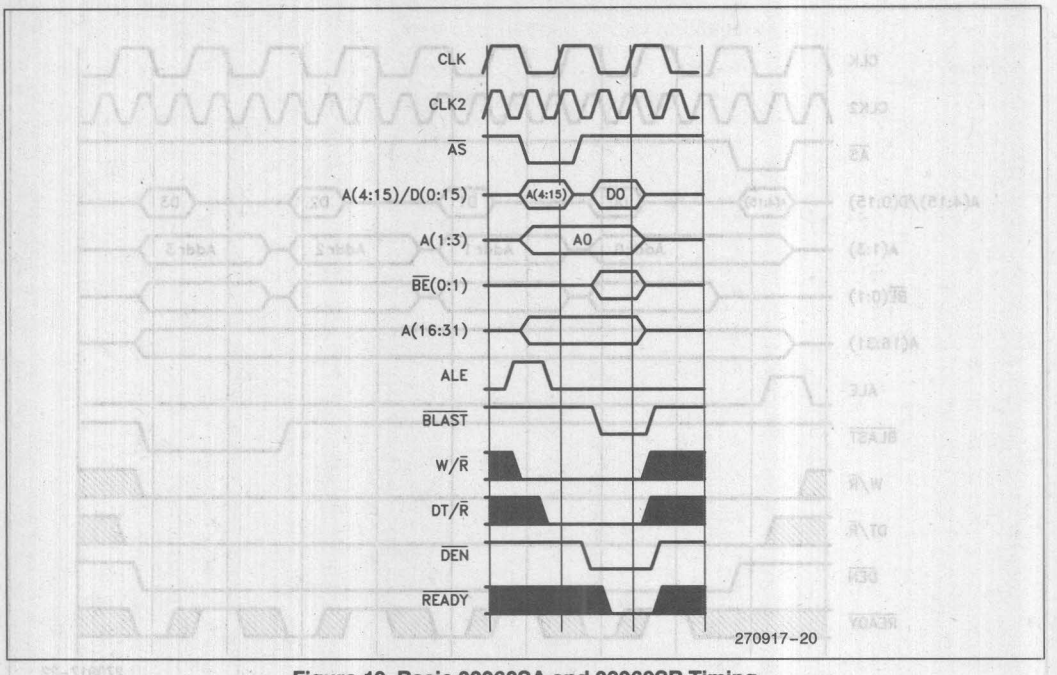


Figure 19. Basic 80960SA and 80960SB Timing

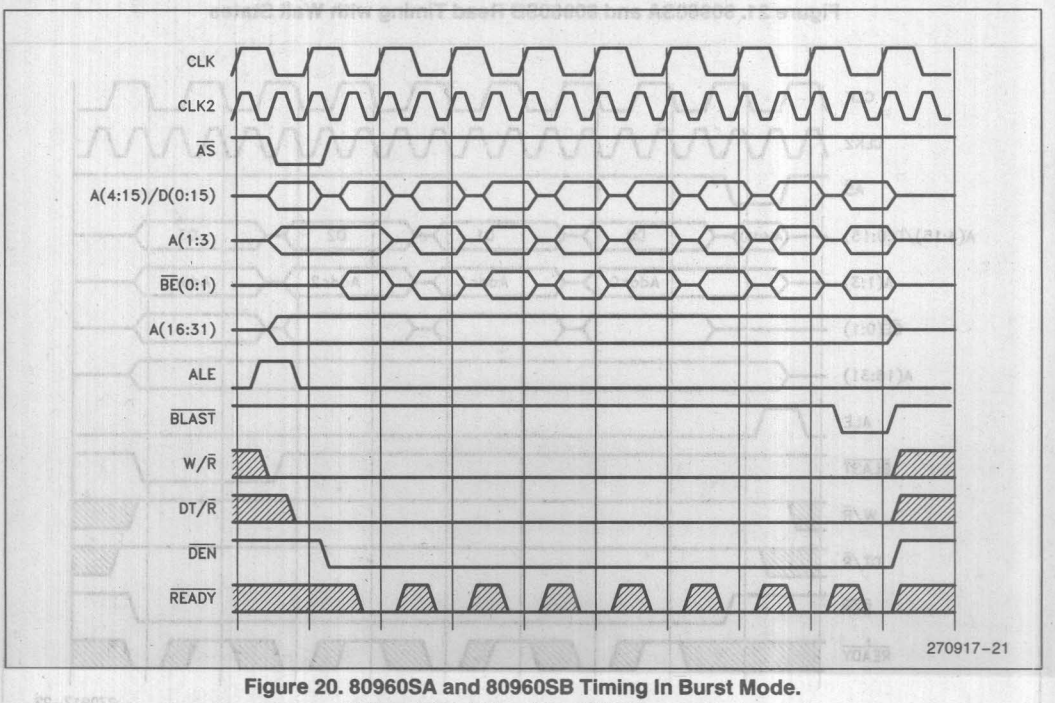


Figure 20. 80960SA and 80960SB Timing In Burst Mode. A Four Word Read Burst Is Shown.

6

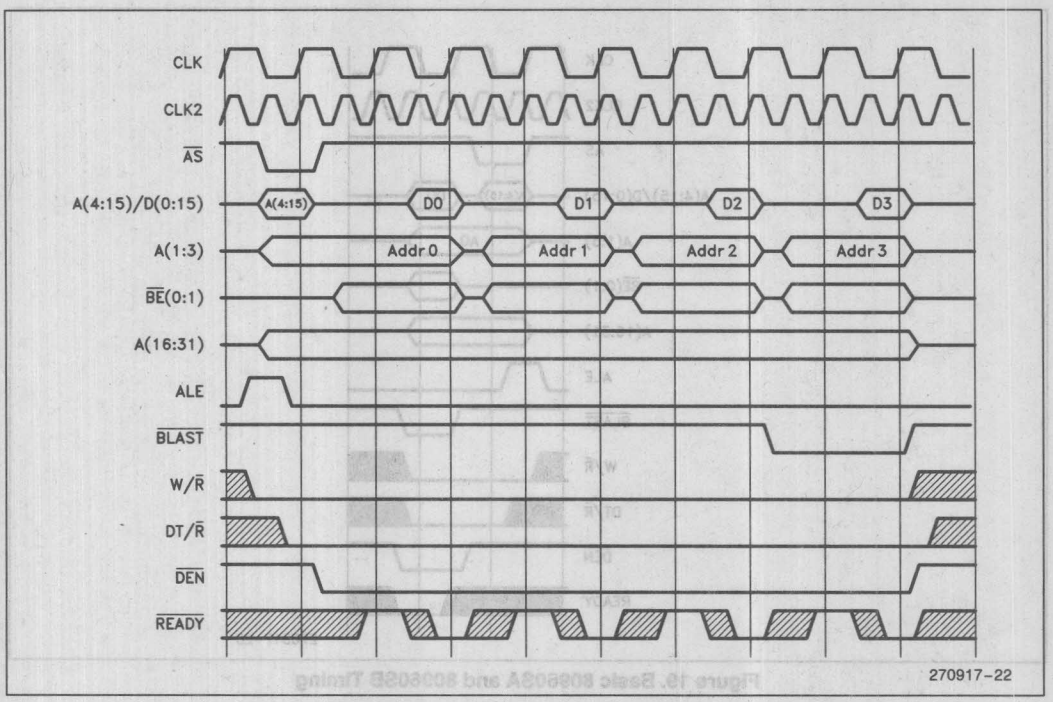


Figure 21. 80960SA and 80960SB Read Timing with Wait States

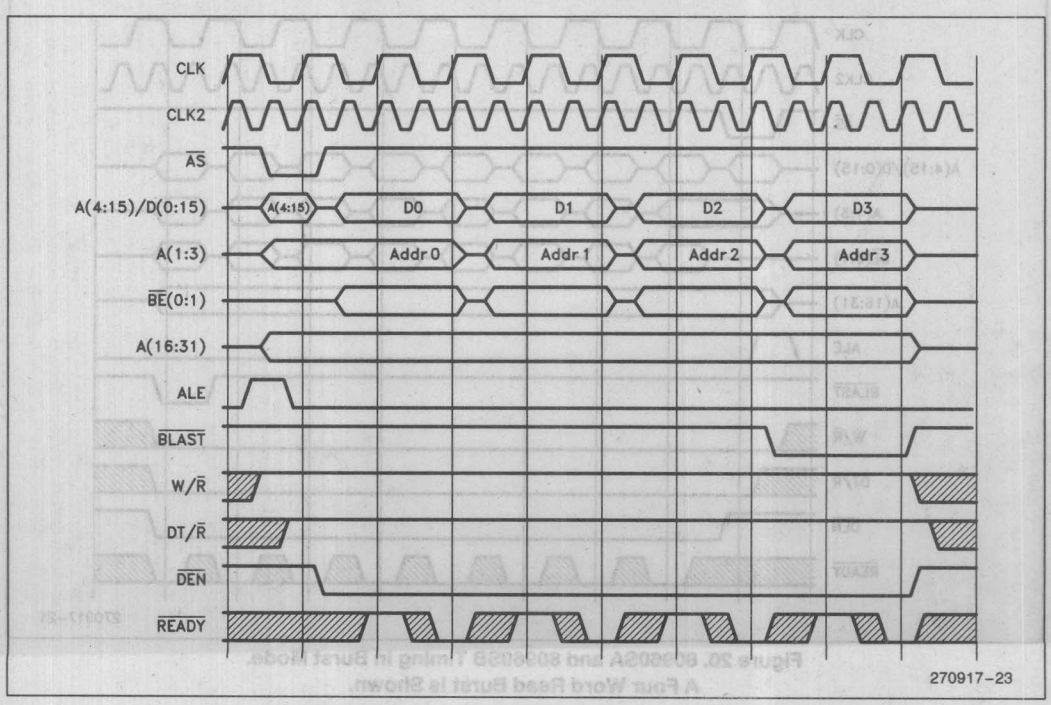


Figure 22. 80960SA and 80960SB Write Timing with Wait States

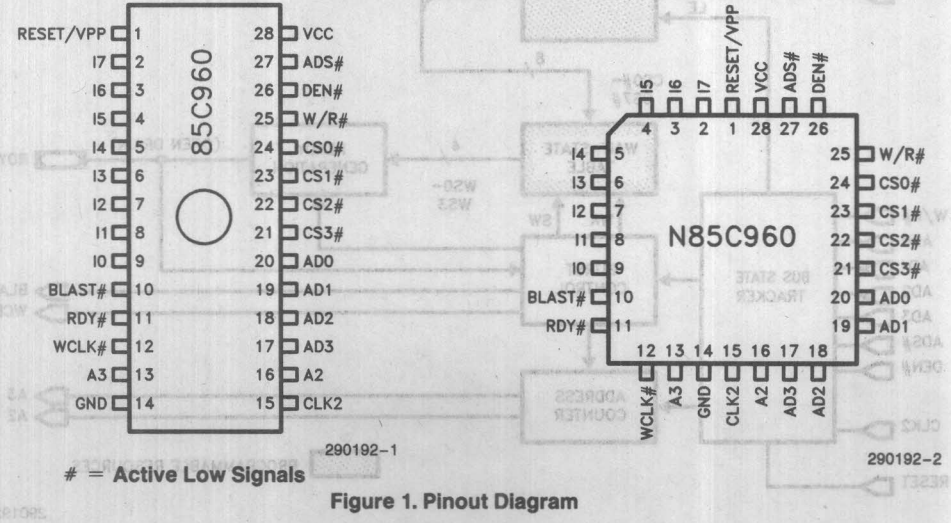
Memories & Peripherals Data Sheets

7

85C960
1-MICRON CHMOS
80960 K-SERIES BUS CONTROL μPLD

- **Burst Logic, Ready Control, and Address Decode Support for 80960 KA/KB Embedded Controllers in Single Chip**
- **Burst Logic Supports Both Standard and New Generation "Burst Mode" Memories and Peripherals**
- **Ready/Timing Control Supports 0–15 Wait States across 8 Address Ranges, Read/Write Accesses, Burst Transactions**
- **8 Dedicated Inputs Decoded into 8 Latched Chip Selects (4 External/ Internal; 4 Internal Only)**
- **Operates with 80960KA/KB at 20 MHz and 25 MHz**
- **I_{CC} = 50 mA Max.**
- **UV Erasable (CerDIP) or OTP™**
- **100% Generically Testable Logic Array**
- **Based on Low Power CHMOS IIIE* Technology**
- **Available in 28-Pin 300-mil CerDIP and PDIP Packages and in 28-Pin PLCC Package**
  (See Packaging Spec., Order Number #231369)

*CHMOS is a patented technology of Intel Corporation.



= Active Low Signals

Figure 1. Pinout Diagram

August 1990
Order Number: 290192-002

GENERAL DESCRIPTION

The Intel 85C960 is a single-chip burst/ready/decode μPLD (Microcomputer Programmable Logic Device) designed to interface 80960 KA/KB embedded controllers to system memory and I/O. The 85C960 provides programmable chip selects, a programmable read/write access wait state/ready generator, and burst address (A2, A3) cycling. Burst transaction cycling of A2, A3, and WCLK# (Write Clock) is also supported for intelligent peripherals on the bus.

For its programmable functions, the 85C960 uses advanced EPROM cells as logic array and wait-state table memory elements. Coupled with Intel's proprietary CHMOS IIIE technology, the result is a programmable device able to support Intel's 32-bit 80960 KA/KB embedded controllers at speeds up to 25 MHz.

ARCHITECTURE DESCRIPTION

The 85C960 μPLD integrates burst control, ready generation, and chip select decoding into a single device. Figure 2 shows the architecture of the 85C960. Table 1 lists and describes each signal on the device. The 85C960 replaces 6–10 separate PLD/discrete logic devices in small- and medium-sized 80960 systems. For medium- to large-sized systems, the 85C960 can be supplemented with an additional decoder, such as the 85C508, and a second 85C960. Figure 3 shows a single 85C960 in a typical application.

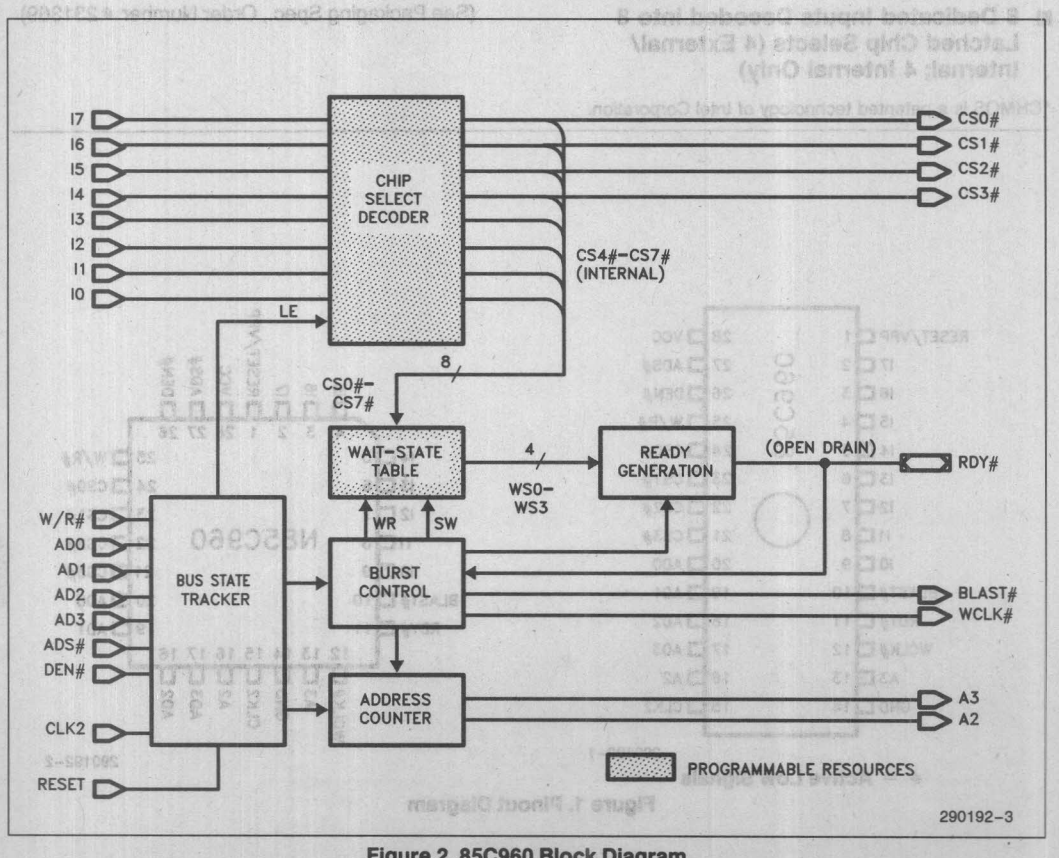


Figure 2. 85C960 Block Diagram

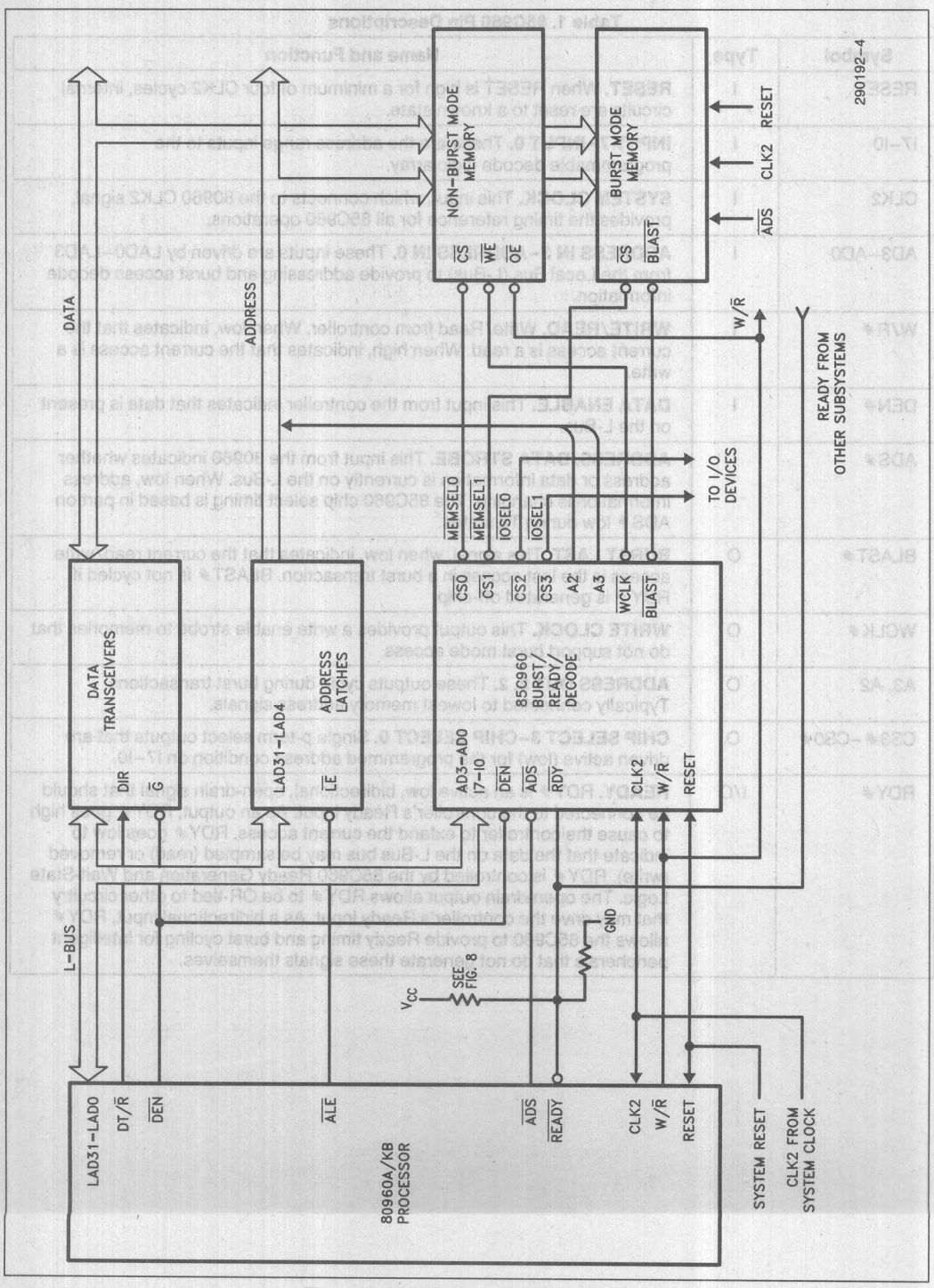


Figure 3. 85C960 in an 80960 System

Table 1. 85C960 Pin Descriptions

Symbol	Type	Name and Function
RESET	I	**RESET.** When RESET is high for a minimum of four CLK2 cycles, internal circuits are reset to a known state.
I7–I0	I	**INPUT 7–INPUT 0.** These are the address range inputs to the programmable decode logic array.
CLK2	I	**SYSTEM CLOCK.** This input, which connects to the 80960 CLK2 signal, provides the timing reference for all 85C960 operations.
AD3–AD0	I	**ADDRESS IN 3–ADDRESS IN 0.** These inputs are driven by LAD0–LAD3 from the Local Bus (L-Bus) to provide addressing and burst access decode information.
W/R#	I	**WRITE/READ.** Write/Read from controller. When low, indicates that the current access is a read. When high, indicates that the current access is a write.
DEN#	I	**DATA ENABLE.** This input from the controller indicates that data is present on the L-Bus.
ADS#	I	**ADDRESS/DATA STROBE.** This input from the 80960 indicates whether address or data information is currently on the L-Bus. When low, address information is changing. The 85C960 chip select timing is based in part on ADS# low during Ta states.
BLAST#	O	**BURST LAST.** This signal, when low, indicates that the current read/write access is the last access in a burst transaction. BLAST# is not cycled if RDY# is generated off-chip.
WCLK#	O	**WRITE CLOCK.** This output provides a write enable strobe to memories that do not support burst mode access.
A3, A2	O	**ADDRESS OUT 3, 2.** These outputs cycle during burst transactions. Typically connected to lowest memory address signals.
CS3#–CS0#	O	**CHIP SELECT 3–CHIP SELECT 0.** Single p-term select outputs that are driven active (low) for the programmed address condition on I7–I0.
RDY#	I/O	**READY.** RDY# is an active low, bidirectional, open-drain signal that should be connected to the controller's Ready input. As an output, RDY# goes high to cause the controller to extend the current access. RDY# goes low to indicate that the data on the L-Bus bus may be sampled (read) or removed (write). RDY# is controlled by the 85C960 Ready Generation and Wait-State Logic. The open-drain output allows RDY# to be OR-tied to other circuitry that may drive the controller's Ready input. As a bidirectional input, RDY# allows the 85C960 to provide Ready timing and burst cycling for intelligent peripherals that do not generate these signals themselves.

80960 L-Bus (Local Bus) cycles are monitored by the **Bus State Tracker** to synchronize the functional blocks in the 85C960 to the L-Bus. CLK2 provides the timing reference for all 85C960 operations.

Four external chip selects (CS0#–CS3#) are generated by the programmable **Chip Select Decoder.** These four signals provide decoded selects to memory and I/O devices and are routed to the programmable **Wait-State Table** so that the 85C960 can generate RDY# at the appropriate time. Four additional selects are decoded (internal only) and routed to the Wait-State Table so that the 85C960 can generate RDY# for up to four additional address ranges.

The **Ready Generation** block generates RDY# to the controller under control of the **Wait-State Table.** Depending on the contents programmed into this table and the current type of access, from 0–15 wait states can be introduced into each bus cycle. An independent wait state value can be chosen for each select and each access type. Four access types are possible: read first, read subsequent, write first, and write subsequent.

The **Burst Control** and **Address Counter** blocks control burst transaction timing to memory and I/O. Note that the RDY# pin is sampled by the Burst Control block to allow the 85C960 to generate burst transaction timing for other bus peripherals. WCLK# provides a write enable strobe for memory and I/O that do not support burst mode. BLAST# informs burst-mode devices that the current access is the last one in a burst transaction. A2 and A3 are cycled to select the address location for each access.

FUNCTIONAL DESCRIPTION

The following paragraphs provide a detailed description of each functional block in the 85C960 μPLD.

Chip Select Decoder

The Chip Select Decoder, shown in Figure 4, is a high speed, single p-term (product-term) latched decoder circuit with eight inputs (I0–I7) and eight latched outputs. Each output goes low when its associated product term is true. Four of these outputs (CS0#–CS3#) are available externally to be used as device selects. The remaining four outputs (CS4#–CS7#) are available internally so that the 85C960 can provide ready and burst timing for four more device selects. (The actual selects for these four additional devices/resources must be generated by external logic.)

The input to each latch is a single NAND p-term that can be connected to the dedicated inputs. The true and complements of all inputs (I7–I0) are available to all eight NAND p-terms.

Each intersecting point in the logic array is connected or not connected based on the value programmed in the EPROM array. Initially (EPROM erased state), no connections exist between any p-term and any input. Connections can be made by programming the appropriate EPROM cells. Since p-terms are implemented as NANDs, a true condition on a p-term drives the output low. Current consumption is higher when both true and complement p-terms for the same input are programmed.

Selects are latched on the falling edge of an internal Latch Enable (LE), which is generated from ADS#, DEN#, and CLK2. The proper combination of these signals occurs during an 80960 address state (Ta). Figure 5 shows the relationship of the internal LE and external chip selects to the three signals at the end of a Ta state. All selects are cleared to an inactive high state at the start of a recovery state. (Tr). All eight selects (four external and four internal) are routed to the Wait-State Table.

Wait State Table

Chip selects, WR (Write/Read), and SW (Subsequent Word) feed the Wait-State Table. Each chip select points to a set of four wait state values while WR and SW determine which of the four values to route to the Ready Generation block (see Figure 6). The four values are grouped into read and write groups with each group having a value for the first access and subsequent access (second through fourth). The four-bit wait-state value is sent to the Ready Generation block (via WS0#–WS3#) to be used as an initial count value. If two selects are active, the resulting count value is the logical bit AND of the two individual values. If more than two selects are active and the individual count values are not the same, the resulting count value is indeterminate. If no select is active, no count value is loaded (and the Ready Generation circuit is disabled).

Ready Generation

RDY# is high at the start of each burst transaction. The RDY Generator begins to count down from the wait state value, decrementing the counter at the start of each wait state. When the internal counter reaches 0000, RDY# is pulled low (CLK2c during the data state). On the next CLK2c edge (for a wait state), RDY# is released, allowing an external resistor to pull RDY# high. Figure 7 shows the timing for a four-word burst write transaction with 1 wait state for the first access and 0 wait states for the remaining three accesses (Burst Write 1-0-0-0).

RDY# is an open-drain I/O pin, which must be connected to pullup and pulldown resistors as shown in Figure 8. During a wait-state access, RDY# is pulled high to cause the controller to extend the current access so that the memory or peripheral chip has time to present data to the bus (read), or sample data on the bus (write). RDY# is released on the CLK2a edge of a Tr state. If a Read or Write access occurs without a chip select having been decoded on-chip, the RDY# output buffer is disabled and RDY# is sampled as an input. This allows the 85C960 to cycle A2, A3, and WCLK# to provide burst transaction timing for other bus controllers. RDY# may be OR-tied with other bus controllers so they can access the processor Ready signal.

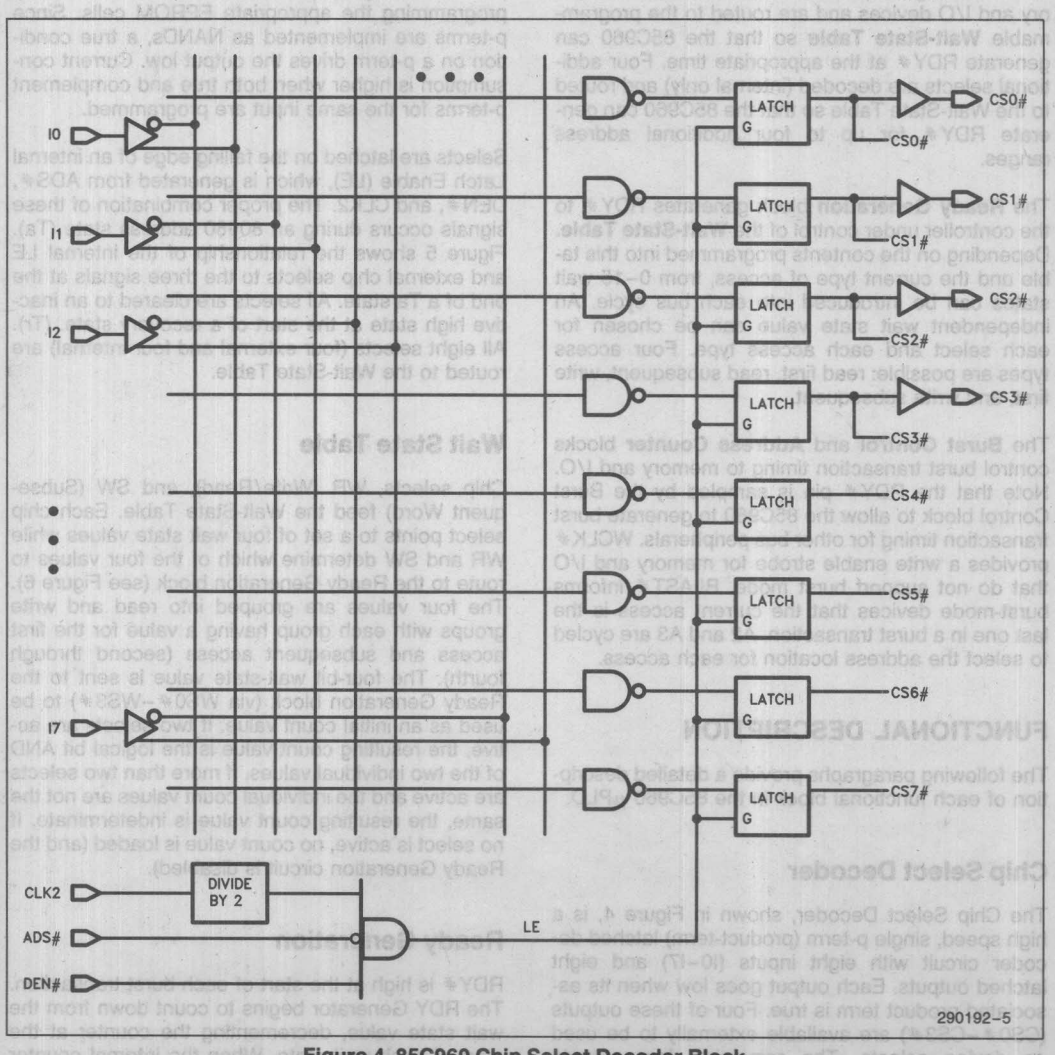
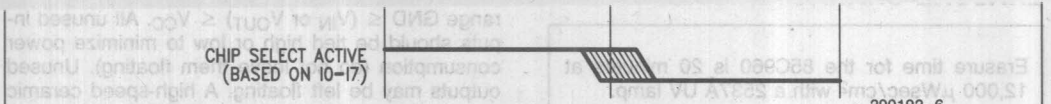


Figure 4. 85C960 Chip Select Decoder Block



Latch opens when CLK2 and DEN# go high and ADS# goes low.
Latch closes when DEN# goes low or ADS# or CLK2 go high.

Figure 5. Internal LE and External Chip Select Timing

Burst Transactions

AD3, AD2 are latched to indicate the starting address of a burst transaction. The 85C960 places these two signals out on A3 and A2, respectively, then cycles the two addresses upward until the last access of the burst. The 85C960 assumes that the processor handles splitting of the burst transaction when a 16-byte boundary is crossed.

AD0 and AD1 specify the size of the burst transfer in double-words as shown in Table 2.

Table 2. AD0–AD1 vs Burst Size

AD1	AD0	No. of Words Transferred
0	0	1
0	1	2
1	0	3
1	1	4

WCLK#, BLAST# Generation

WCLK# is the write enable signal for writing to non-burst mode memories. When low, address outputs A2 and A3 are valid. Its trailing edge (low-to-high transition) can be used to latch data into non-burst mode memories. WCLK# is only provided during writes; during reads, WCLK# remains high.

BLAST# indicates that the current access is the last access in a burst transaction. BLAST# is used by burst-mode memories to reset internal address counters. BLAST# is not cycled when RDY# is generated off-chip.

POWER-ON CHARACTERISTICS

85C960 inputs and outputs begin responding 1 μs (max.) after V_{CC} power-up (V_{CC} = 4.75V) or after a power-loss/power-up sequence. RESET must be synchronous to CLK2 and must be held high for a minimum of 4 clock cycles after V_{CC} reaches 4.75 V. After 4 clock cycles, A2 and A3 are high, CS0#–CS3# (and CS4#–CS7#), BLAST#, WCLK# are high, and the open drain RDY# signal is inactive.

7

Select CS0f#	Write/Read	
	WR = 0 (Read)	WR = 1 (Write)
SW=0 (First Word)	msb lsb 0000	msb lsb 0000
SW=1 (Subsequent Word)	msb lsb 0011	msb lsb 0010

msb = most significant bit
lsb = least significant bit

Figure 6. Example Wait-State Entries for CS0f#

ERASURE CHARACTERISTICS

Erasure time for the 85C960 is 20 minutes at 12,000 μWsec/cm^2 with a 2537Å UV lamp.

Erasure characteristics of the device are such that erasure begins to occur upon exposure to light with wavelengths shorter than approximately 4000Å. It should be noted that sunlight and certain types of fluorescent lamps have wavelengths in the 3000Å–4000Å range. Data shows that constant exposure to room level fluorescent lighting could erase the typical 85C960 in approximately two years, while it would take approximately two weeks to erase the device when exposed to direct sunlight. If the device is to be exposed to these lighting conditions for extended periods of time, conductive opaque labels should be placed over the device window to prevent unintentional erasure.

The recommended erasure procedure for the 85C960 is exposure to shortwave ultraviolet light with a wavelength of 2537Å. The integrated dose (i.e., UV intensity $\times$ exposure time) for erasure should be a minimum of fifteen (15) Wsec/cm^2. The erasure time with this dosage is approximately 20 minutes using an ultraviolet lamp with a 12,000 μW/cm^2 power rating. The device should be placed within 1 inch of the lamp tubes during exposure. The maximum integrated dose the 85C960 can be exposed to without damage is 7258 Wsec/cm^2 (1 week at 12,000 μW/cm^2). Exposure to high intensity UV light for longer periods may cause permanent damage to the device.

LATCH-UP IMMUNITY

All of the input, output, and clock pins of the device have been designed to resist latch-up which is inherent in inferior CMOS processes. The 85C960 is designed with Intel's proprietary 1-micron CHMOS EPROM process. Thus, each of the pins will not experience latch-up with currents up to $\pm$100 mA and voltages ranging from $-$0.5V to (V_{CC} + 0.5V). The programming pin is designed to resist latch-up to the 13.5V max. device limit.

DESIGN RECOMMENDATIONS

For proper operation, it is recommended that all input and output pins be constrained to the voltage range GND $\leq$ (V_{IN} or V_{OUT}) $\leq$ V_{CC}. All unused inputs should be tied high or low to minimize power consumption (do not leave them floating). Unused outputs may be left floating. A high-speed ceramic decoupling capacitor of at least 0.2 μF must be connected directly between the V_{CC} and GND pin.

As with all CMOS devices, ESD handling procedures should be used with the 85C960 to prevent damage to the device during programming, assembly, and test.

FUNCTIONAL TESTING

Since the programmable sections of the 85C960 are controlled by EPROM elements, the device is completely testable during the manufacturing process. Each programmable EPROM bit controlling the internal logic is tested using application independent test patterns. EPROM cells in the device are 100% tested for programming and erasure. After testing, the devices are erased before shipments to the customers. No post-programming tests of the EPROM array are required.

The testability and reliability of EPROM-based programmable logic devices is an important feature over similar devices based on fuse technology. Fuse-based programmable logic devices require a user to perform post-programming tests to insure device functionality. During the manufacturing process, tests on fuse-based parts can only be performed in very restricted ways in order to avoid preprogramming the array.

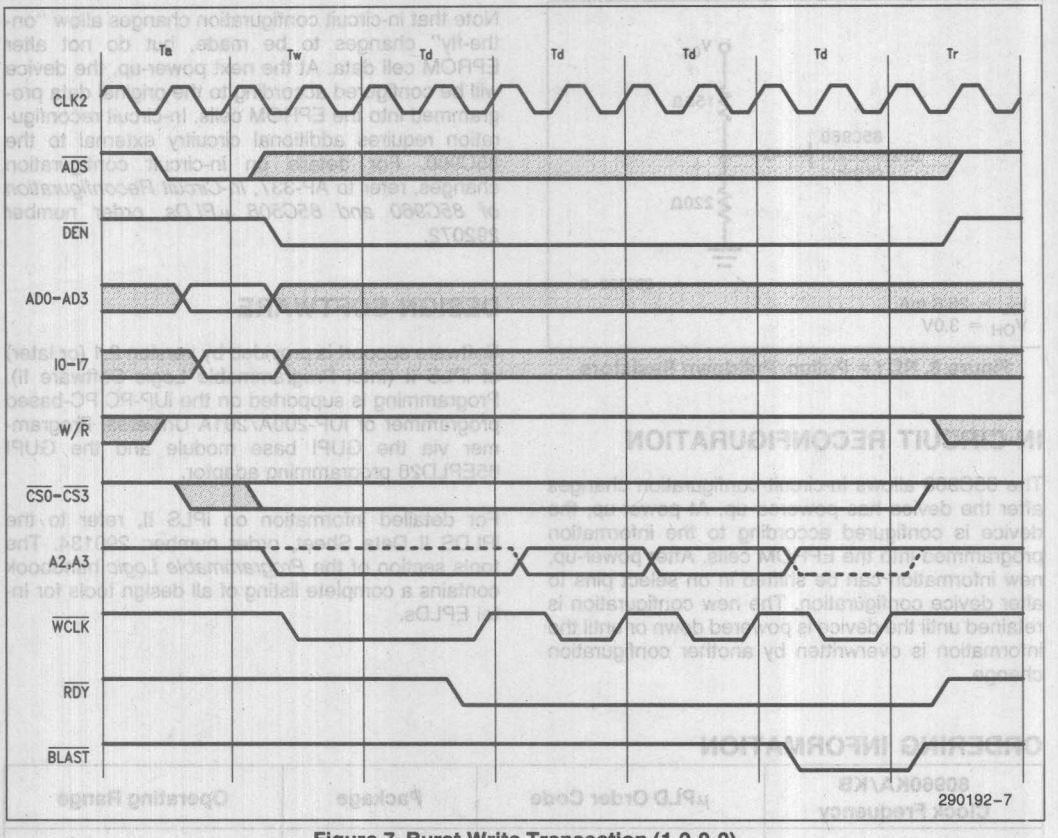


Figure 7. Burst Write Transaction (1-0-0-0)

Figure 8. RDY# Pullup/Pulldown Resistors

IN-CIRCUIT RECONFIGURATION

The 85C960 allows in-circuit configuration changes after the device has powered up. At power-up, the device is configured according to the information programmed into the EPROM cells. After power-up, new information can be shifted in on select pins to alter device configuration. The new configuration is retained until the device is powered down or until the information is overwritten by another configuration change.

Software support is provided by version 2.1 (or later) of iPLS II (Intel Programmable Logic Software II). Programming is supported on the iUP-PC PC-based programmer or iUP-200A/201A Universal Programmer via the GUPI base module and the GUPI 85EPLD28 programming adaptor.

For detailed information on iPLS II, refer to the iPLDS II Data Sheet, order number: 290134. The tools section of the *Programmable Logic* handbook contains a complete listing of all design tools for Intel EPLDs.

ORDERING INFORMATION

80960KA/KB Clock Frequency	μPLD Order Code	Package	Operating Range
20 MHz	*D85C960-20	CERDIP	Commercial
	N85C960-20	PLCC	
25 MHz	*D85C960-25	CERDIP	Commercial
	N85C960-25	PLCC	

*Only windowed CERDIP allows UV-erase.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage (V_{CC})(1) ..... −2.0V to +7.0V

Programming Supply Voltage (V_{PP})(1) ..... −2.0V to +13.5V

D.C. Input Voltage (V_I)(1, 2) ... −0.5V to V_{CC} + 0.5V

Storage Temperature (T_{stg}) ..... −65°C to +150°C

Ambient Temperature (T_A)(3) ..... −10°C to +85°C

NOTES:
1. Voltages with respect to GND.
2. Minimum D.C. input is −0.5V. During transitions, the inputs may undershoot to −2.0V or overshoot to +7.0V for periods of less than 20 ns under no load conditions.
3. Under bias. Extended Temperature versions are also available.

NOTICE: This is a production data sheet. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

RECOMMENDED OPERATING CONDITIONS

Symbol	Parameter	Min	Max	Units
V_{CC}	Supply Voltage	4.75	5.25	V
V_{IN}	Input Voltage	0	V_{CC}	V
V_O	Output Voltage	0	V_{CC}	V
T_A	Operating Temperature	0	+70	°C

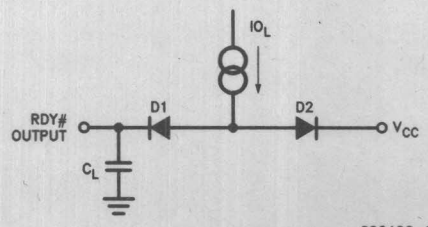
7

D.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = 5.0V ± 5%)

Symbol	Parameter	Min	Typ	Max	Unit	Test Conditions
V_{IH1}(4)	High Level Input Voltage (All Inputs except for ADS#, AD0–AD3, DEN#, and W/R#)	2.0		V_{CC} + 0.3	V	
V_{IH2}(4)	High Level Input Voltage for ADS#, AD0–AD3, DEN#, and W/R#	2.2			V	
V_{IL}(4)	Low Level Input Voltage	−0.3		0.8	V	
V_{OH}	High Level Output Voltage	2.4			V	I_{OH} = −4.0 mA D.C., V_{CC} = Min.
V_{OL1}	Low Level Output Voltage			0.4	V	I_{OL} = 4.0 mA D.C., V_{CC} = Min., C_L = 30 pF
V_{OL2}	Low Level Output Voltage for A2, A3			0.45	V	I_{OL} = 24 mA D.C., V_{CC} = Min., C_L = 60 pF
V_{OL3}	Low Level Output Voltage for Open Drain (RDY#)			0.5	V	I_{OL} = 30 mA D.C., V_{CC} = Min., C_L = 30 pF
I_I	Input Leakage Current			±10	μA	V_{CC} = Max., GND ≤ V_{IN} ≤ V_{CC}
I_{OZ}	Output Leakage Current			±10	μA	V_{CC} = Max., GND ≤ V_{OUT} ≤ V_{CC}
I_{SC}(5)	Output Short Circuit Current	−30		−90	mA	V_{CC} = Max., V_{OUT} = 0.5V
I_{CC}	Power Supply Current		10	50	mA	V_{CC} = Max., V_{IN} = V_{CC} or GND, No Load, CLK2 = 50 MHz

NOTES:
4. Absolute values with respect to device GND; all over and undershoots due to system or tester noise are included.
5. Not more than 1 output should be tested at a time. Duration of that test should not exceed 1 second.

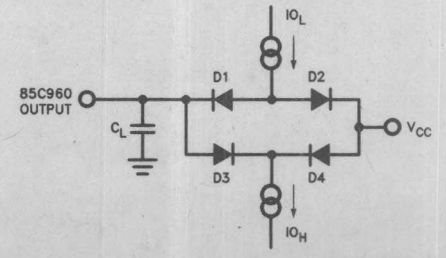
A.C. TESTING LOAD CIRCUIT (RDY#)



290192-9

See D.C. Characteristics Table for Current and Capacitance Specifications.
D1 and D2 are matched.

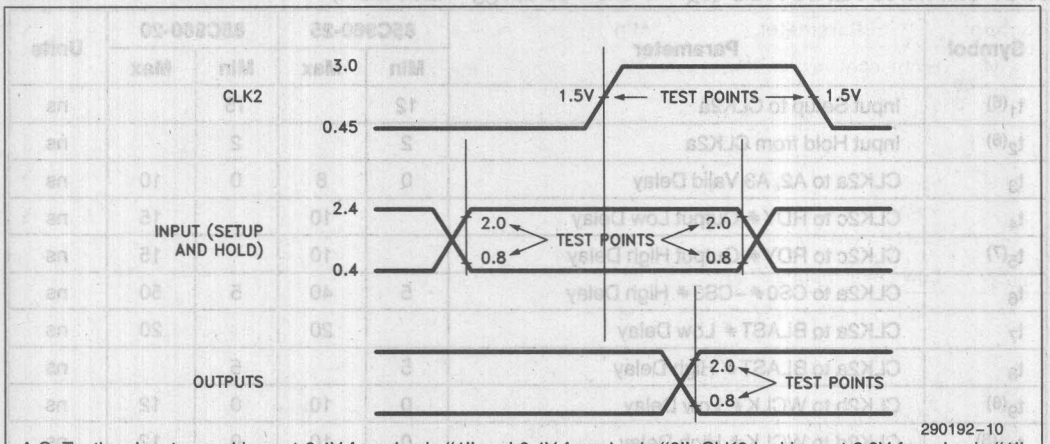
A.C. TESTING LOAD CIRCUIT (ALL OUTPUTS EXCEPT RDY#)



290192-18

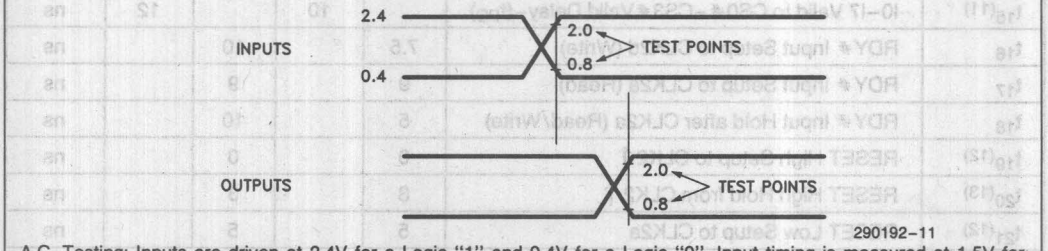
See D.C. Characteristics Table for Current and Capacitance Specifications.
D1 and D2 are matched
D3 and D4 are matched

A.C. TESTING WAVEFORM—SYNCHRONOUS INPUTS AND OUTPUTS



A.C. Testing: Inputs are driven at 2.4V for a Logic "1" and 0.4V for a Logic "0". CLK2 is driven at 3.0V for a Logic "1" and 0.45V for a Logic "0". Timing Measurements made relative to CLK2 are made from 1.5V on CLK2. Inputs and outputs are measured at 2.0V for a high and 0.8V for a low. Device input rise and fall times are less than 3 ns.

A.C. TESTING WAVEFORM—ASYNCHRONOUS INPUTS AND OUTPUTS



A.C. Testing: Inputs are driven at 2.4V for a Logic "1" and 0.4V for a Logic "0". Input timing is measured at 1.5V for high-to-low and low-to-high transitions. Outputs are measured at 2.0V for a high and 0.8V for a low. Device input rise and fall times are less than 3 ns.

7

A.C. CHARACTERISTICS (T_A = 0°C to +70°C, V_{CC} = 5.0V ±5%)

Symbol	Parameter	85C960-25		85C960-20		Units
		Min	Max	Min	Max	
t_1(6)	Input Setup to CLK2a	12		15		ns
t_2(6)	Input Hold from CLK2a	2		2		ns
t_3	CLK2a to A2, A3 Valid Delay	0	8	0	10	ns
t_4	CLK2c to RDY# Output Low Delay		10		15	ns
t_5(7)	CLK2c to RDY# Output High Delay		10		15	ns
t_6	CLK2a to CS0#–CS3# High Delay	5	40	5	50	ns
t_7	CLK2a to BLAST# Low Delay		20		20	ns
t_8	CLK2a to BLAST# High Delay	5		5		ns
t_9(8)	CLK2b to WCLK# Low Delay	0	10	0	12	ns
t_{10}(8)	CLK2d to WCLK# High Delay	0	10	0	12	ns
t_{11}(9)	ADS# Low to CS0#–CS3# Low Delay		10		12	ns
t_{12}(9)	CLK2c to CS0#–CS3# Low Delay		12		15	ns
t_{13}(10)	I0–I7 Setup to CLK2a	5		7		ns
t_{14}(10)	I0–I7 Hold from CLK2a	2		2		ns
t_{15}(11)	I0–I7 Valid to CS0#–CS3# Valid Delay–(t_{PD})		10		12	ns
t_{16}	RDY# Input Setup to CLK2d (Write)	7.5		10		ns
t_{17}	RDY# Input Setup to CLK2a (Read)	9		9		ns
t_{18}	RDY# Input Hold after CLK2a (Read/Write)	5		10		ns
t_{19}(12)	RESET High Setup to CLK2 ↑	0		0		ns
t_{20}(13)	RESET High Hold from CLK2 ↑	3		3		ns
t_{21}(12)	RESET Low Setup to CLK2a	5		5		ns

NOTES:
6. Applies to ADS#, DEN#, W/R#, and AD0–AD3. DEN# is high during the entire Ta state in 80960 KA/KB systems.
7. RDY# is an open-drain output. Specified time includes RDY# output float delay and pull-up/pull-down resistors (Figure 8). RDY# remains low for a minimum of 10 ns at the start of a Tr state and goes high by CLK2a of the next Tx state.
8. Minimum WCLK# pulse width is one clock period minus 3 ns. For example, at 25 MHz: 20 ns − 3 ns = a 17 ns minimum WCLK# pulse.
9. Chip Select Decoder latches are transparent flow-through types. Latches open when ADS# is low, DEN# is high, and CLK2 goes high during the middle of a Tx state (CLK2c). Since DEN# is high during the entire Ta state in 80960 KA/KB systems, only CLK2c and ADS# are specified.
10. Chip Select Decoder latches are transparent flow-through types. Latches close when ADS# is high or DEN# is low, or when CLK2 goes high at the start of a Tx state (CLK2a) after the latches have opened. Since ADS# is low and DEN# is high at the end of a Ta in 80960 KA/KB systems, setup and hold times are specified with reference to CLK2a only.
11. Propagation delay while latches are open (transparent); one output switching (high-to-low).
12. RESET must be held high for a minimum of 4 CLK2 cycles (80960 specifies 41 CLK2 cycles minimum).
13. RESET must hold after the low-to-high transition immediately prior to CLK2a. CLK2a is defined as the first low-to-high transition after RESET goes low.

CLK2 EDGES

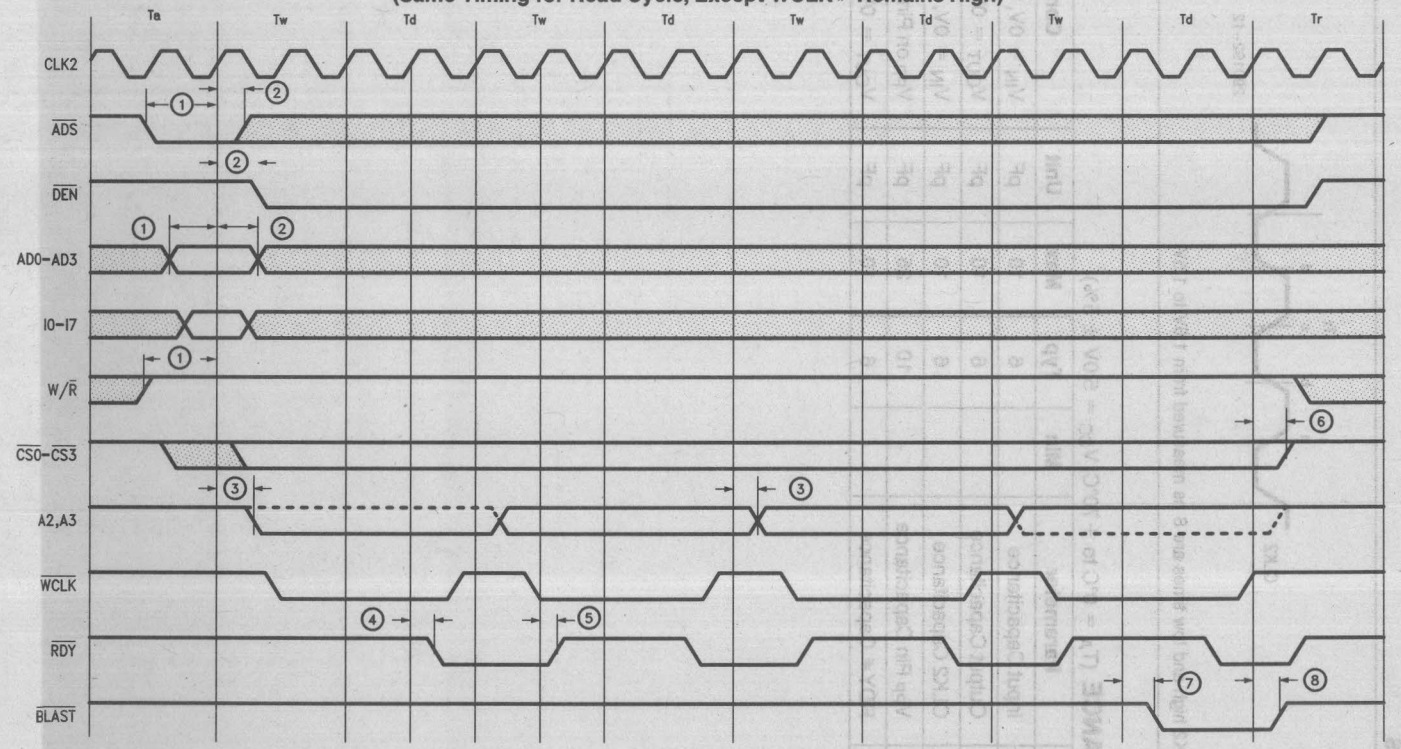
NOTE:
Minimum CLK2 high and low times are 8 ns measured from 1.5V to 1.5V.

CAPACITANCE (T_A = 0°C to +70°C; V_{CC} = 5.0V ± 5%)

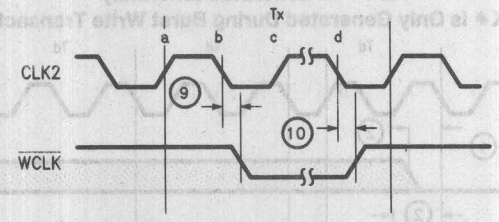
Symbol	Parameter	Min	Typ	Max	Unit	Conditions
C_{IN}	Input Capacitance		6	10	pF	V_{IN} = 0V, f = 1.0 MHz
C_{OUT}	Output Capacitance		6	10	pF	V_{OUT} = 0V, f = 1.0 MHz
C_{CLK}	CLK2 Capacitance		6	10	pF	V_{IN} = 0V, f = 1.0 MHz
C_{VPP}	V_{PP} Pin Capacitance		10	25	pF	V_{PP} on Pin 1 (RESET)
C_{RDY}	RDY# Capacitance		6	10	pF	V_{OUT} = 0V, f = 1.0 MHZ

7

4 Word Burst Write with 1 Wait State on Each Access
RDY# is Generated by the 85C960
(Same Timing for Read Cycle, Except WCLK# Remains High)

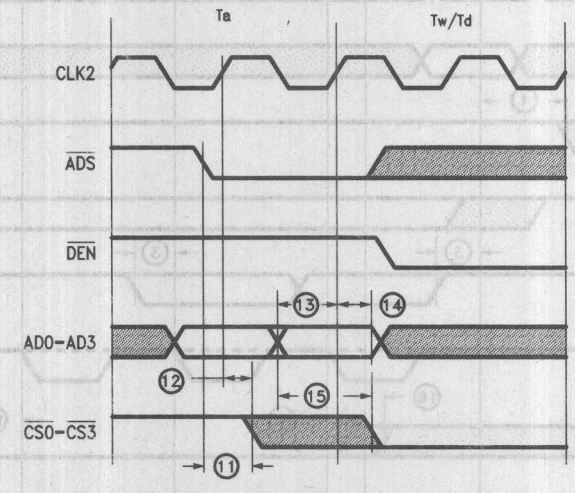


WCLK# TIMING



290192-14

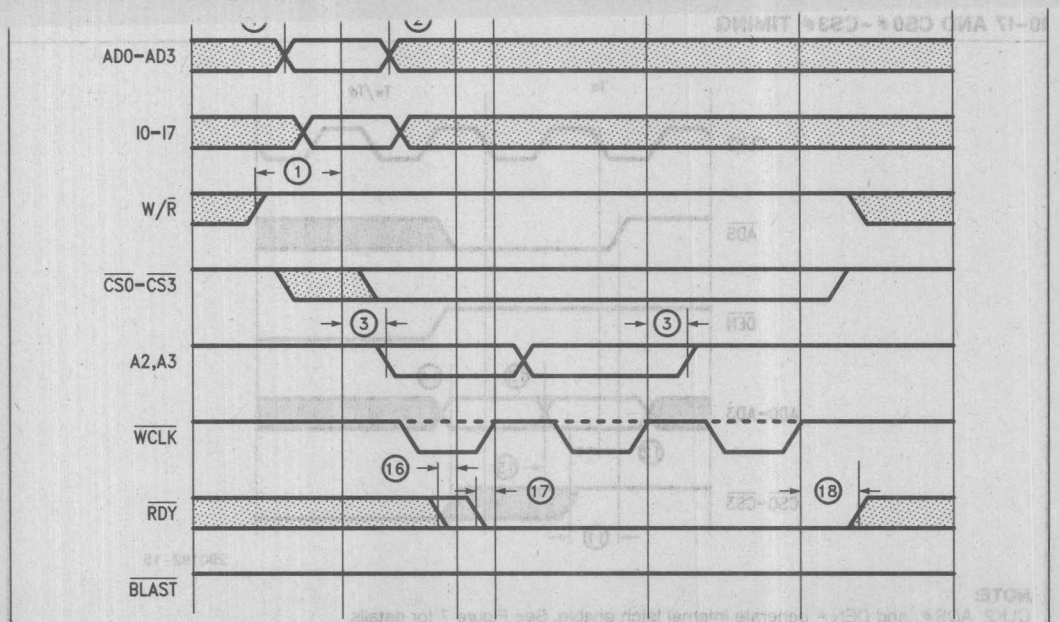
I0-I7 AND CS0#-CS3# TIMING



290192-15

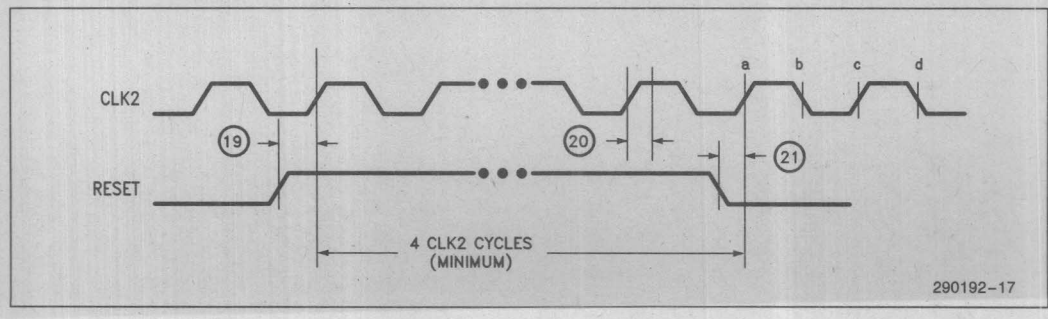
NOTE:
CLK2, ADS#, and DEN# generate internal latch enable. See Figure 7 for details.

7



290192–16

RESET INPUT TIMING



290192–17

27960CX
PIPELINED BURST ACCESS 1M (128K x 8) CHMOS EPROM

- **Synchronous 4 Byte Data Burst Access**
- **No Glue Interface to 80960CA**
- **High Performance Clock to Data Out**
  - **— Zero Wait State Data to Data Burst**
  - **— Up to 33 MHz 80960CA Performance**
- **Asynch Microcontroller Reset Function**
  - **— Returns to Known State with High-Z Outputs**
- **Pipelined Addressing for Optimal Bus Bandwidth on 80960CA**
  - **— Next Addressing Overlaps Last Data Byte**
- **CHMOS III-E for High Performance and Low Power**
  - **— 125 mA Active, 30 mA Standby**
  - **— TTL Compatible Inputs**
- **1 Mbit Density Configures as 128K x 8**
  - **— Upgrade Path to 512K x 8**

Intel's 27960CX is a 5V only, 1,048,576 bit, Erasable Programmable Read Only Memory, organized as 128K words of 8 bits. It is a member of a new family of high performance EPROMs with synchronous burst access.

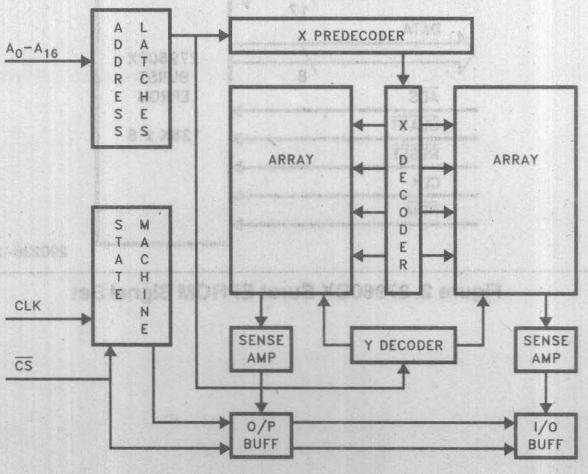
The 27960CX provides a no glue synchronous burst interface to the 80960CA bus. Internally the 27960CX is organized in 4 byte blocks, in which each byte is accessed sequentially. The internal state machine is factory configured to generate either 1 or 2 wait-states between the address and first data byte. High performance outputs provide zero wait-state data to data accesses at clock frequencies up to 33 MHz.

Pipelining capability allows addresses to overlap previous data, further optimizing bus bandwidth in 80960CA applications. An asynchronous microcontroller $\overline{\text{RESET}}$ feature puts the outputs in the high impedance state and takes the internal state machine to a known state where a new burst access can begin.

The 27960CX is available in either 44-lead Cerquad (reprogrammable) or PLCC packages. Cerquad allows for code changes in the R & D environment while PLCC provides optimum cost effectiveness during production. Two No Connects (NC) on the package allow for an upgrade to 4 Mbits (512K x 8).

The 27960CX is manufactured on Intel's 1 micron CHMOS III-E technology. The Quick-Pulse Programming™ algorithm provides fast, reliable programming with throughput under 17 seconds for optimized equipment.

*CHMOS is a Patented Process of Intel Corporation.



290236-1

Figure 1. 27960CX Burst EPROM Block Diagram

7

January 1991
Order Number: 290236-004

27960CX BURST EPROM

EPROMs are established as the preferred code storage device in embedded applications. The non-volatile, flexible, reliable, cost effective EPROM makes a product easier to design, manufacture and service. Until recently, however, EPROMs could not match the performance needs of high-end systems. The 27960CX was designed to support the 80960CA embedded processor. It utilizes the burst interface to offer near zero wait-state performance without the high cost normally associated with this performance.

In embedded designs, board space and cost must be kept at a minimum without impacting performance and reliability. The 27960CX removes the need for expensive high-speed shadow RAM backed up by slow EPROM or ROM for non-volatile code storage. Code optimization concerns are reduced with "off-chip" code fetches no longer crippling to system performance. FONTs can be run directly out of these EPROMs at the same performance as high-speed DRAMs. With the 27960CX, the EPROM is the ideal code or FONT storage device for your 80960CA system.

*CERQUAD is available in a socket only version.

Architecture

The 27960CX provides a no-glue, synchronous burst interface to the 80960CA's bus. It operates in pipelined or non-pipelined modes. Internally, the 27960CX is organized in 4 byte blocks which are accessed sequentially. A burst access begins on the first clock pulse after $\overline{ADS}$ and $\overline{CS}$ are asserted. The address of the 4 byte block is latched on the rising edge of clock following $\overline{ADS}$. After a preset number of wait-states (1 or 2), data is output one byte at a time on each subsequent clock cycle. A burst access is terminated on the rising edge of clock with $\overline{BLAST}$ asserted. High performance outputs provide zero wait-state data to data accesses at clock frequencies up to 33 MHz. Extra power and ground pins dedicated to the outputs reduce the effects of fast output switching on device performance.

The pipelining capability of the 27960CX allows the address to overlap the last data byte of the burst, further optimizing bus band width in 80960CA applications. In the pipelined mode, with a non-buffered interface, the 27960CX delivers 4 bytes of data in 6 clock cycles at 33 MHz. In a 32-bit configuration, this translates into a read bandwidth of 88 Mbytes/sec. Performance capability of the 27960CX in different 80960CA systems is given in Table I.

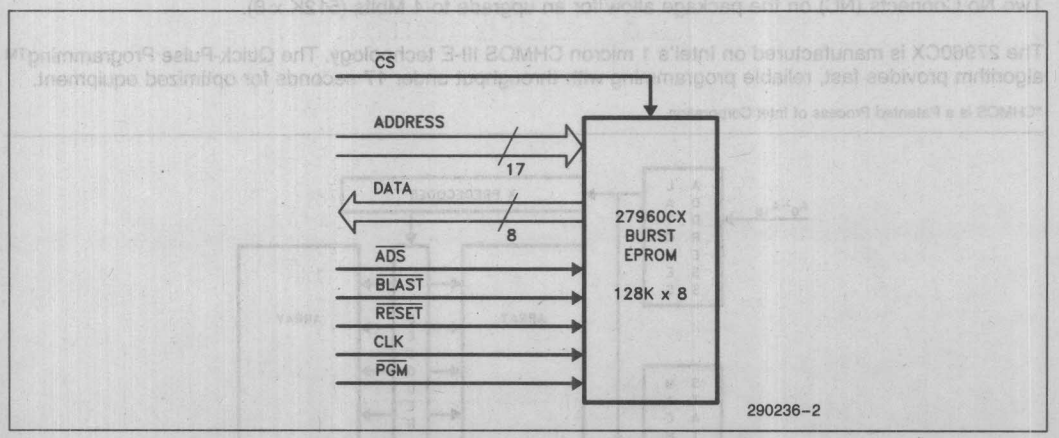


Figure 2. 27960CX Burst EPROM Signal Set

Table 1. Performance Capability

33 MHz 2 WS Non-Buffered: 4 Words/6 Clock Cycles → 88 Mbytes/Sec

ADDR	A_{00}	WS	WS	—	—	—	A_{01}	WS	WS	—	—	—	A_{02}	WS
DATA	—	—	—	D_{00}	D_{01}	D_{02}	D_{03}	—	—	D_{10}	D_{11}	D_{12}	D_{13}	—
PCLK	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_1	C_2	C_3	C_4	C_5	C_6	C_1

25 MHz 2 WS Buffered: 4 Words/6 Clock Cycles → 66 Mbytes/Sec

ADDR	A_{00}	WS	WS	—	—	—	A_{01}	WS	WS	—	—	—	A_{02}	WS
DATA	—	—	—	D_{00}	D_{01}	D_{02}	D_{03}	—	—	D_{10}	D_{11}	D_{12}	D_{13}	—
PCLK	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_1	C_2	C_3	C_4	C_5	C_6	C_1

20 MHz 1 WS Buffered: 4 Words/5 Clock Cycles → 64 Mbytes/Sec

ADDR	A_{00}	WS	—	—	—	A_{01}	WS	—	—	—	A_{02}	WS	
DATA	—	—	D_{00}	D_{01}	D_{02}	D_{03}	—	D_{10}	D_{11}	D_{12}	D_{13}	—	
PCLK	C_1	C_2	C_3	C_4	C_5	C_6	C_1	C_2	C_3	C_4	C_5	C_1	

16 MHz 1 WS Buffered: 4 Words/5 Clock Cycles → 51 Mbytes/Sec

ADDR	A_{00}	WS	—	—	—	A_{01}	WS	—	—	—	A_{02}	WS	
DATA	—	—	D_{00}	D_{01}	D_{02}	D_{03}	—	D_{10}	D_{11}	D_{12}	D_{13}	—	
PCLK	C_1	C_2	C_3	C_4	C_5	C_6	C_1	C_2	C_3	C_4	C_5	C_1	

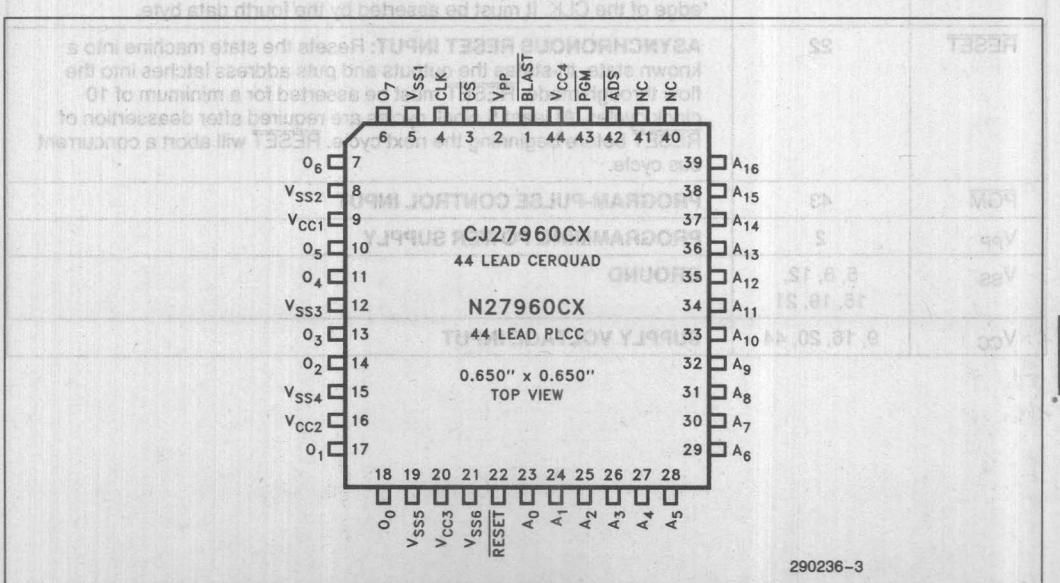


Figure 3. 27960CX 44 Lead PLCC/CERQUAD Pinout

PIN DESCRIPTIONS

Symbol	Pin	Function
A_0–A_{16}	23–39	**ADDRESS INPUTS:** During a burst operation, A_2–A_{16} provides the base address pointing to a block of four consective bytes. A_0 and A_1 select the first byte of the burst access. The 27960CX latches addresses in the first clock cycle. An internal address generator increments addresses A_0 and A_1 for subsequent bytes of the burst.
D_0–D_7	6, 7, 10, 11, 13, 14, 17, 18	**DATA INPUTS/OUTPUTS**
$\overline{ADS}$	42	**ADDRESS STROBE:** Indicates the start of a new bus access. $\overline{ADS}$ is active low in the first clock cycle of a bus access.
$\overline{CS}$	3	**CHIP SELECT:** Master device enable. When asserted (active low) data can be written to and read from the device. In read mode, $\overline{CS}$ enables the state machine and the I/O circuitry. **NOTE:** 1. The address decode path is independent of $\overline{CS}$, i.e., X and Y decoding is always powered up. 2. For programming, $\overline{CS}$ should remain low for the entire cycle. Program and verify functions are done one byte at a time. 3. $\overline{CS}$ going high does not terminate a concurrent burst cycle.
$\overline{BLAST}$	1	**BURST LAST:** Terminates a concurrent burst data cycle at the rising edge of the CLK. It must be asserted by the fourth data byte.
$\overline{RESET}$	22	**ASYNCHRONOUS RESET INPUT:** Resets the state machine into a known state, tri-states the outputs and puts address latches into the flow through mode. $\overline{RESET}$ must be asserted for a minimum of 10 clock cycles. At least 5 clock cycles are required after deassertion of $\overline{RESET}$ before beginning the next cycle. $\overline{RESET}$ will abort a concurrent bus cycle.
$\overline{PGM}$	43	**PROGRAM-PULSE CONTROL INPUT**
V_{PP}	2	**PROGRAMMING POWER SUPPLY**
V_{SS}	5, 8, 12, 15, 19, 21	**GROUND**
V_{CC}	9, 16, 20, 44	**SUPPLY VOLTAGE INPUT**

INTERFACE EXAMPLE

Overview

This example illustrates 8-, 16- and 32-bit wide 27960CX interfaces to the 80960CA. The designs offer a simple "no-glue" interface.

A non-buffered 27960CX system organized as 256K x 32 is shown in Figure 4A. Since the 27960CX is capable of driving a 80 pF load, large, non-buffered systems can be implemented by stacking up to 2 banks of 4 EPROMs, resulting in a 256K x 32 memory subsystem. The input capacitive load seen on the address lines (due to the EPROM only) is 24 pF for a 128K x 32 system and 48 pF for a 256K x 32 system. The EPROM is specified at 6 pF for input capacitance (15 pF max) and 12 pF typical for output capacitance. Larger systems can be implemented with buffers (Figure 4B).

Chip Select Logic

High order address lines are decoded to provide $\overline{CS}$. Qualification with other signals is not required. The chip select logic can be implemented with standard asynchronous decoders, PAL's or PLD's (like Intel's 85C508).

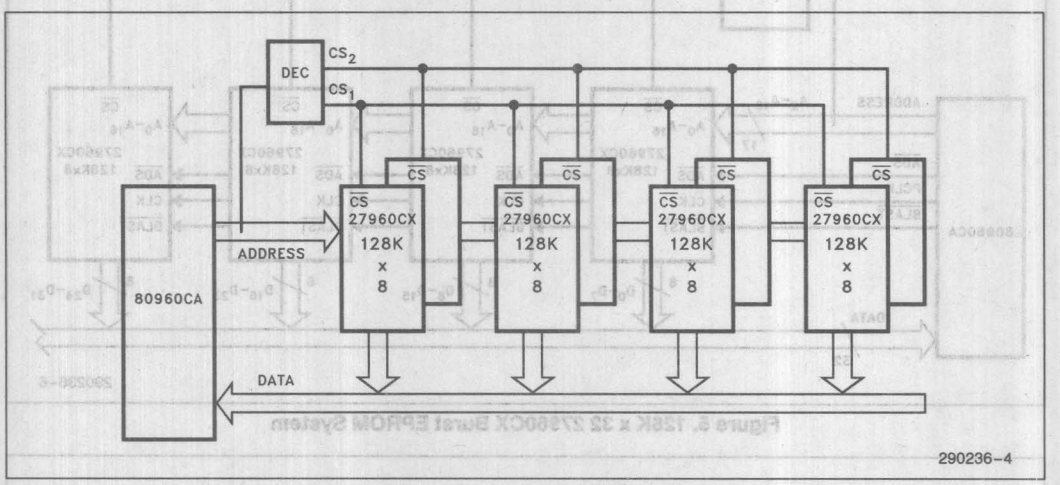


Figure 4A. 256K x 32 Non-Buffered Burst EPROM Memory System

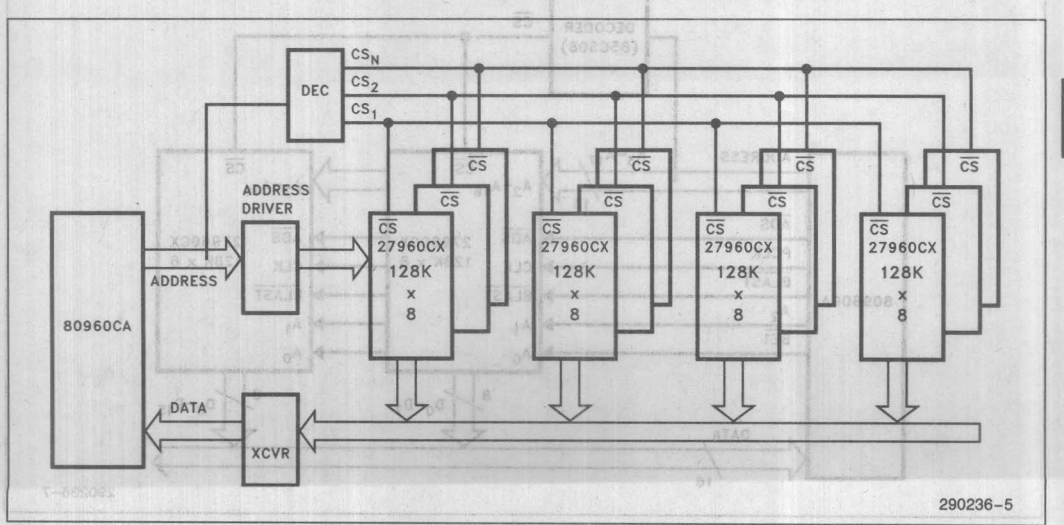


Figure 4B. Buffered Burst EPROM Memory System

7

Schematics

Figure 5 shows a non-buffered, 128K x 32 27960CX EPROM system.

Chip select logic, the only external logic that is required for this interface, can be derived from the global system chip select circuitry.

In a non-buffered, 16-bit system (Figure 6A) $\overline{BE1}$ and A_2 connect to the lower order address bits of the 27960CX. $\overline{BE1}$ connects to A_0 of both EPROMs, while A_2 connects to both A_1's.

In a non-buffered, 8-bit system (Figure 6B) $\overline{BE0}$ and $\overline{BE1}$ connect to A_0 and A_1 respectively.

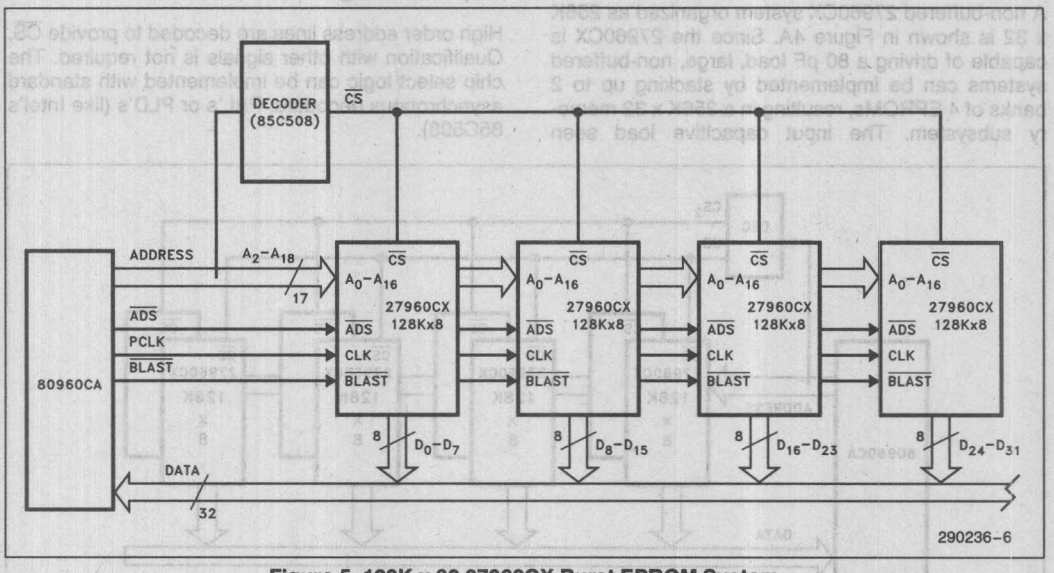


Figure 5. 128K x 32 27960CX Burst EPROM System

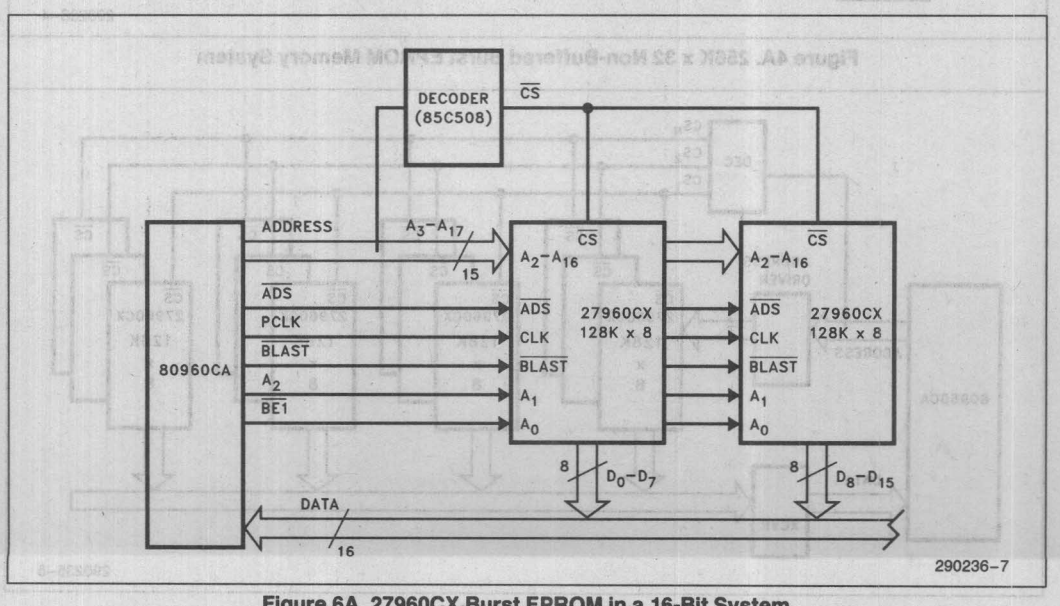


Figure 6A. 27960CX Burst EPROM in a 16-Bit System

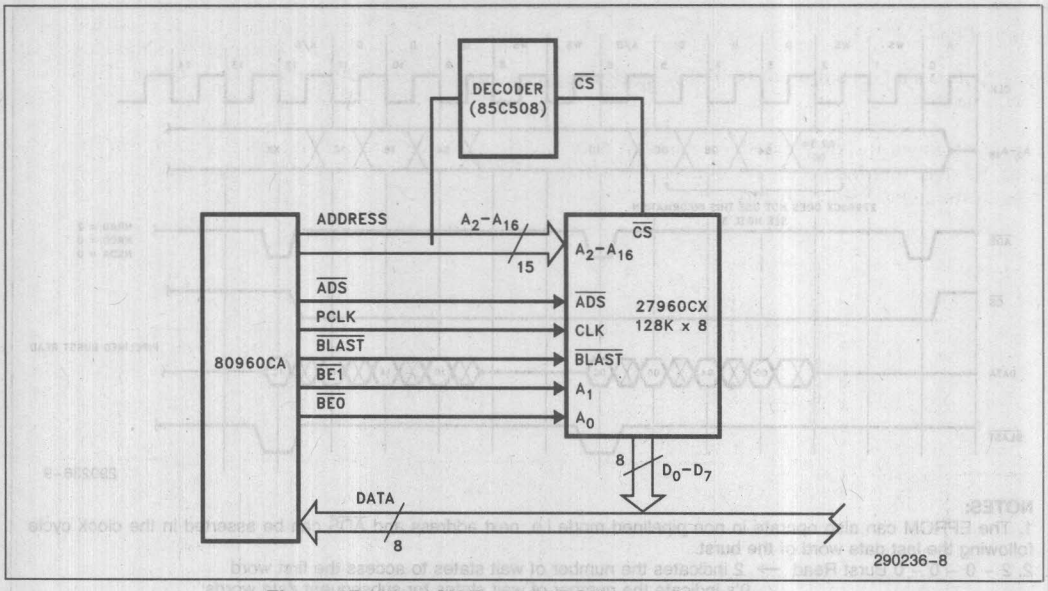


Figure 6B. 27960CX Burst EPROM in a 8-Bit System

Waveforms

Figure 7 shows the timing waveforms of a 27960CX pipelined read in a 32-bit system.

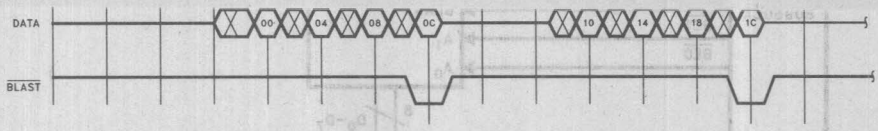
$\overline{CS}$ Setup Time

$\overline{CS}$ setup time is the time between $\overline{CS}$ being asserted and the first CLK rising edge (during the address cycle). Since a memory access begins on the first CLK rising edge after $\overline{ADS}$ and $\overline{CS}$ are asserted, a minimum $\overline{CS}$ setup time of 5 ns (t_{SVCH}) at 33 MHz is required. With the 80960CA's maximum valid address delay of 18 ns at 33 MHz, 7 ns remains for $\overline{CS}$ decoding logic.

Bootup

The wait state configuration (1 or 2), of the 27960CX is programmed by the user into the 80960CA Region Table parameters of NRAD, NRDD, and NXDA. NRDD is always 0 for the 27960CX.

7



NOTES:
1. The EPROM can also operate in non pipelined mode i.e, next address and $\overline{ADS}$ can be asserted in the clock cycle following the last data word of the burst.
2. 2 – 0 – 0 – 0 Burst Read → 2 indicates the number of wait states to access the first word
0's indicate the number of wait states for subsequent data words:
0 in this case!
3. 27960CX latches addresses on the falling edge of clock cycle 1 after sampling $\overline{CS}$ and $\overline{ADS}$ it has an internal address generator which increments addresses for subsequent words of the burst. It ignores the states of A_2, A_3 and $\overline{BE0}$–$\overline{BE3}$ during a burst.

Figure 7. Two Cycles of a 27960CX 2 Wait State 4 Byte Read (2–0–0–0 Burst Read) in a 32 Bit System

During boot-up (Figure 8), the 80960CA picks up it's Region Table data from addresses FFFF FF00; FFFF FF04; FFFF FF08 and FFFF FF0C. Only the least significant byte of each of the above four 32-bit accesses is used to configure the Region Table. For boot-up, the wait-state parameters NRAD and NXDA default to 31 and 3 respectively. During boot-up, the 27960CX will wrap around the first word of the four-word burst and hold the first word until $\overline{BLAST}$ is asserted.

27960CX DEVICE NAMES

The device names on the 27960CX were derived as mnemonics that correspond to the number of wait states and expected operating frequency for the device. For example, the 25 MHz, 2 wait state 27960CX is named 27960C2-25.

AC TIMING DERIVATIONS

The AC timings for the 27960CX were generated specifically to meet the requirements of the 80960CA microprocessor. In each case the applicable 80960CA clock frequency and AC timing were taken together with an address buffer delay (if needed) and a typical 2 ns guardband to generate the 27960CX AC timing. Worst case timings were always assumed. The example below shows how the 27960C2-33 $tavc_0h$ timing was derived.

@33 MHz the clock cycle is ~30 ns.
t_{OV2} of the 80960CA is 3 ns – 16 ns.
Typical 2 ns guardband.

27960C2-33 $tavc_0h$ = 30 ns – 16 ns – 2 ns
= 12 ns

On timings where the EPROM is faster than the microprocessor, we specified the time required by the EPROM and left the excess time as additional system guardband.

Decoders are needed for the systems chip select decoding. For the 27960CX timings we assumed a 10 ns chip select decoder for 20 MHz and 16 MHz and a 7 ns decoder for 25 MHz and 33 MHz systems. The example below shows how the 27960C2-33 tsvch timing was derived.

@33 MHz the clock cycle is ~30 ns.
t_{OV2} of the 80960CA is 3 ns – 16 ns.
Decoder = 7 ns

27960C2-33 tsvch = 30 ns – 16 ns – 7 ns
= 7 ns

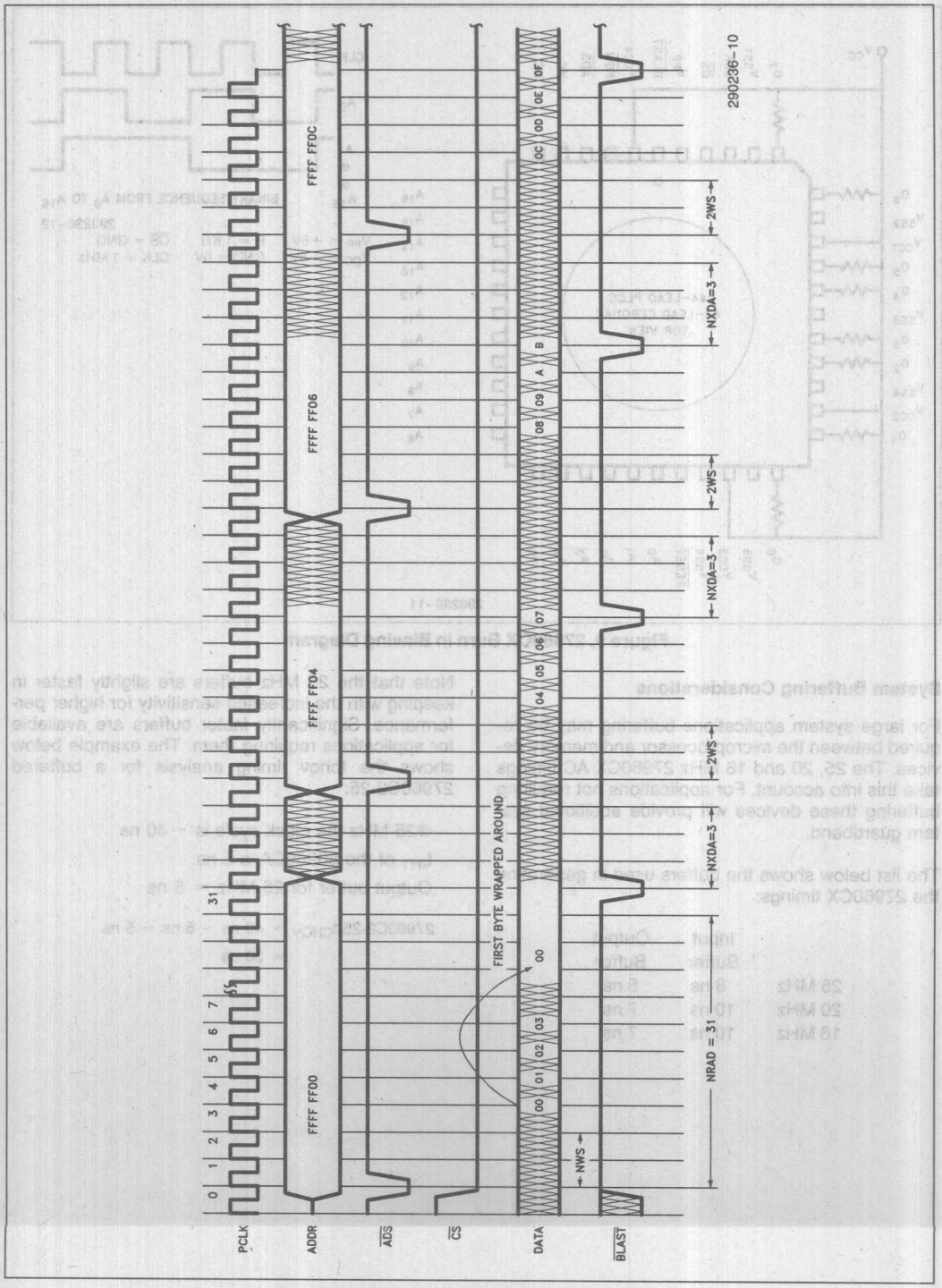


Figure 8. 27960CX/80960CA Bootup Timing

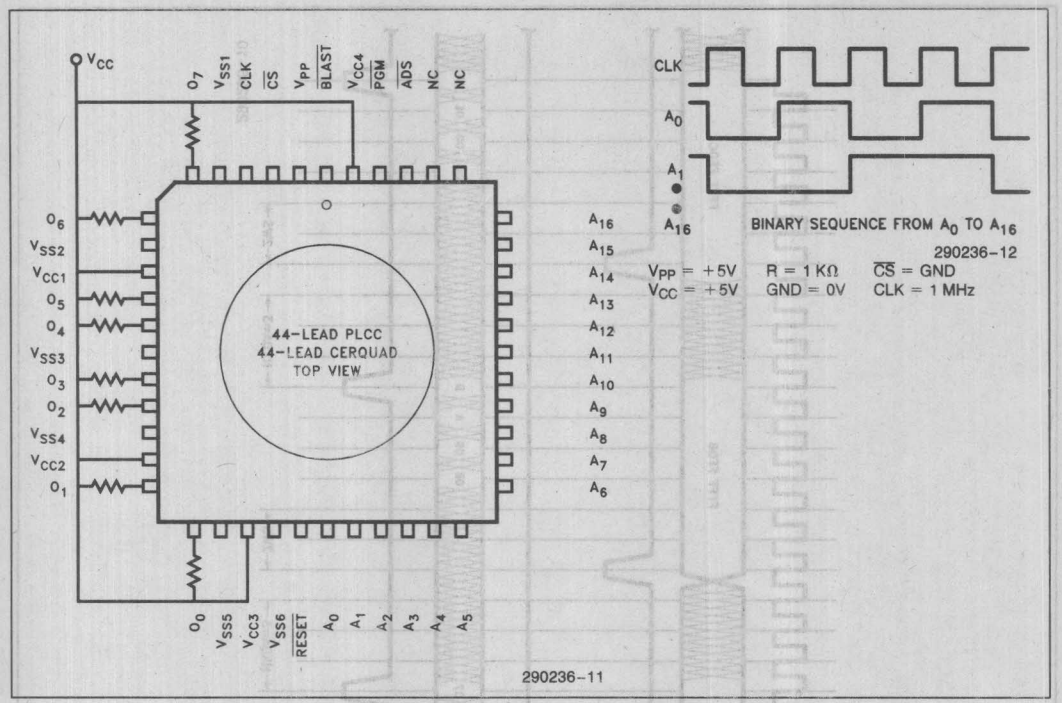


Figure 9. 27960CX Burn in Biasing Diagram

System Buffering Considerations

For large system applications buffering may be required between the microprocessor and memory devices. The 25, 20 and 16 MHz 27960CX AC timings take this into account. For applications not requiring buffering these devices will provide additional system guardband.

The list below shows the buffers used in generating the 27960CX timings:

	Input Buffer	Output Buffer
25 MHz	8 ns	5 ns
20 MHz	10 ns	7 ns
16 MHz	10 ns	7 ns

Note that the 25 MHz buffers are slightly faster in keeping with the increased sensitivity for higher performance. Significantly faster buffers are available for applications requiring them. The example below shows the tchqv timing analysis for a buffered 27960C2-25.

@25 MHz the clock cycle is ~40 ns.

t_{IH1} of the 80960CA is 5 ns.

Output buffer for 25 MHz = 5 ns

27960C2-25 t_{CHQV} = 40 ns − 5 ns − 5 ns
= 30 ns

ABSOLUTE MAXIMUM RATINGS*

Read Operating Temperature . . . . . 0°C to +70°C(8)

Case Temperature Under Bias . . −10°C to +80°C(8)

Storage Temperature . . . . . −65°C to +125°C

All Input or Output Voltages with Respect to Ground . . . . . −0.6V to +6.5V(4)

Voltage on A_9 with Respect to Ground . . . . . −0.6V to +13.0V(4)

V_{PP} Supply Voltage with Respect to Ground . . . . . −0.6V to +14.0V(4)

V_{CC} Supply Voltage with Respect to Ground . . . . . −0.6V to +7.0V(4)

NOTICE: This data sheet contains preliminary information on new products in production. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

READ OPERATION

DC CHARACTERISTICS $0°C < T_A +70°C$, $V_{CC} = 5V \pm 10\%$, TTL Inputs

Symbol	Parameter		Notes	Min	Max	Unit	Test Condition
I_{LI}	Input Load Current				1	μA	$V_{IN} = 5.5V$
I_{LO}	Output Leakage Current				10	μA	$V_{OUT} = 5.5V$
I_{PP}	V_{PP} Load Current Read				10	μA	$V_{PP} = 0$ to V_{CC}, $\overline{PGM} = V_{IH}$
I_{SB}	V_{CC} Standby	Switching	2		45	mA	$\overline{CS} = V_{IH}$, f = 33 MHz
		Stable	2		30	mA	$\overline{CS} = V_{IH}$
I_{CC}	V_{CC} Active Current		1, 3, 7		125	mA	$\overline{CS} = V_{IL}$, f = 33 MHz, $I_{OUT} = 0$ mA
V_{IL}	Input Low Voltage		4	−0.5	0.8	V	
V_{IH}	Input High Voltage			2.0	$V_{CC} + 1$	V	
V_{OL}	Output Low Voltage				0.45	V	$I_{OL} = 2.1$ mA
V_{OH}	Output High Voltage		5	$V_{CC} - 0.8$		V	$I_{OH} = -100$ μA
			5	2.4		V	$I_{OH} = -400$ μA
I_{OS}	Output Short Circuit		6		100	mA	

NOTES:
1. Maximum current is with outputs unloaded.
2. I_{CC} standby current assumes no output loading i.e., $I_{OH} = I_{OL} = 0$ mA.
3. I_{CC} is the sum of current through $V_{CC3} + V_{CC4}$ and does not include the current through V_{CC1} and V_{CC2}. (V_{CC1} and V_{CC2} supply power to the output drivers. V_{CC3} and V_{CC4} supply power to the reset of the device.)
4. Minimum DC input voltage on input and output pins is −0.5V. During transitions, this level may undershoot to −2.0V for periods less than 20 ns.
5. Maximum DC voltage on input and output pins is $V_{CC} + 0.5V$ which may overshoot to $V_{CC} + 2.0V$ for periods less than 20 ns.
6. One output shorted for no more than one second. I_{OS} is sampled but not 100% tested.
7. I_{CC} max measured with a 0.11 μF capacitor between V_{CC} and V_{SS}.
8. This specification defines commercial product operating temperatures.

7

EXPLANATION OF AC SYMBOLS

The nomenclature used for timing parameters are as per IEEE STD 662-1980 IEEE Standard Terminology for Semiconductor Memory.

Each timing symbol has five characters. The first is always a "t" (for time). The second character represents a signal name. e.g., (CLK, $\overline{ADS}$, etc.). The third character represents the signal's level (high or low) for the signal indicated by the second character. The fourth character represents a signal name at which a transition occurs marking the end of the time interval being specified.

The fifth character represents the signal level indicated for the fourth character. The list below shows character representations.

A:	Address	R:	$\overline{Reset}$
B:	$\overline{BLAST}$	Q:	Data
C:	Clock	S:	$\overline{CS}$
H:	Logic High Level	t:	Time
L:	$\overline{ADS}$/Logic Low Level	V:	Valid
P:	V_{PP} Programming Voltage	Z:	Tri-state Level
X:	No longer a valid "driven" logic level		

AC CHARACTERISTICS: READ OPERATION $0°C < T_A < +70°C, V_{CC} = 5V \pm 10\%$

Versions				27960C2-33		27960C2-25		27960C1-20		27960C1-16		Unit
				33 MHz 2 Wait State		25 MHz 2 Wait State		20 MHz 1 Wait State		16 MHz 1 Wait State		
No.	Symbol	Parameter	Notes	Min	Max	Min	Max	Min	Max	Min	Max	
1	t_{AVC_0H}	Address Valid to CLK High	CLK_0	12		10		14		22		ns
2	t_{C_NHAX}	CLK High to Address Invalid	2	0		0		0		0		ns
3	t_{LLCH}	$\overline{ADS}$ low to CLK High	CLK_0	8		8		14		22		ns
4	t_{CHLH}	CLK high to $\overline{ADS}$ High	5	6	22	6	32	6	36	6	40	ns
5	t_{SVCH}	$\overline{CS}$ Valid to CLK High	1	7		7		6		14		ns
6	t_{C_NHSX}	CLK High to $\overline{CS}$ Invalid	2	0		0		0		0		ns
7	t_{CHQV}	CLK High to Data Valid	7		27		30		35		40	ns
8	t_{CHQX}	CLK High to Data Invalid		5		5		5		5		ns
9	t_{CHQZ}	CLK High to Data High Z	6		25		30		30		30	ns
10	t_{BVCH}	$\overline{BLAST}$ Valid to CLK High		8		8		14		22		ns
11	t_{CHBX}	CLK High to $\overline{BLAST}$ Invalid	3	6	22	6	32	6	36	6	40	ns

NOTES:
1. Valid signal level is meant to be either a logic high or logic low.
2. The subscript N represents the number of wait states for this parameter. $\overline{CS}$ can be de-asserted (high) after the number of wait states (N) has expired and the EPROM will continue to burst out data for the current cycle.
3. BLAST# must be returned high before the next rising clock edge.
4. The sum of $t_{CHQV} + t_{AVCH} + N_{CLK}$ will not equal actual t_{AVQV} if independent test conditions are used to obtain t_{AVCH} and t_{CHQV} (N = number of wait states).
5. $\overline{ADS}$ must be returned high before the next rising clock edge.
6. Sampled, not 100% tested. The transition is measured ±500 mV from steady state voltage.
7. For capacitive loads above 80 pF, t_{CHQV} can be derated by 1 ns/20 pF.

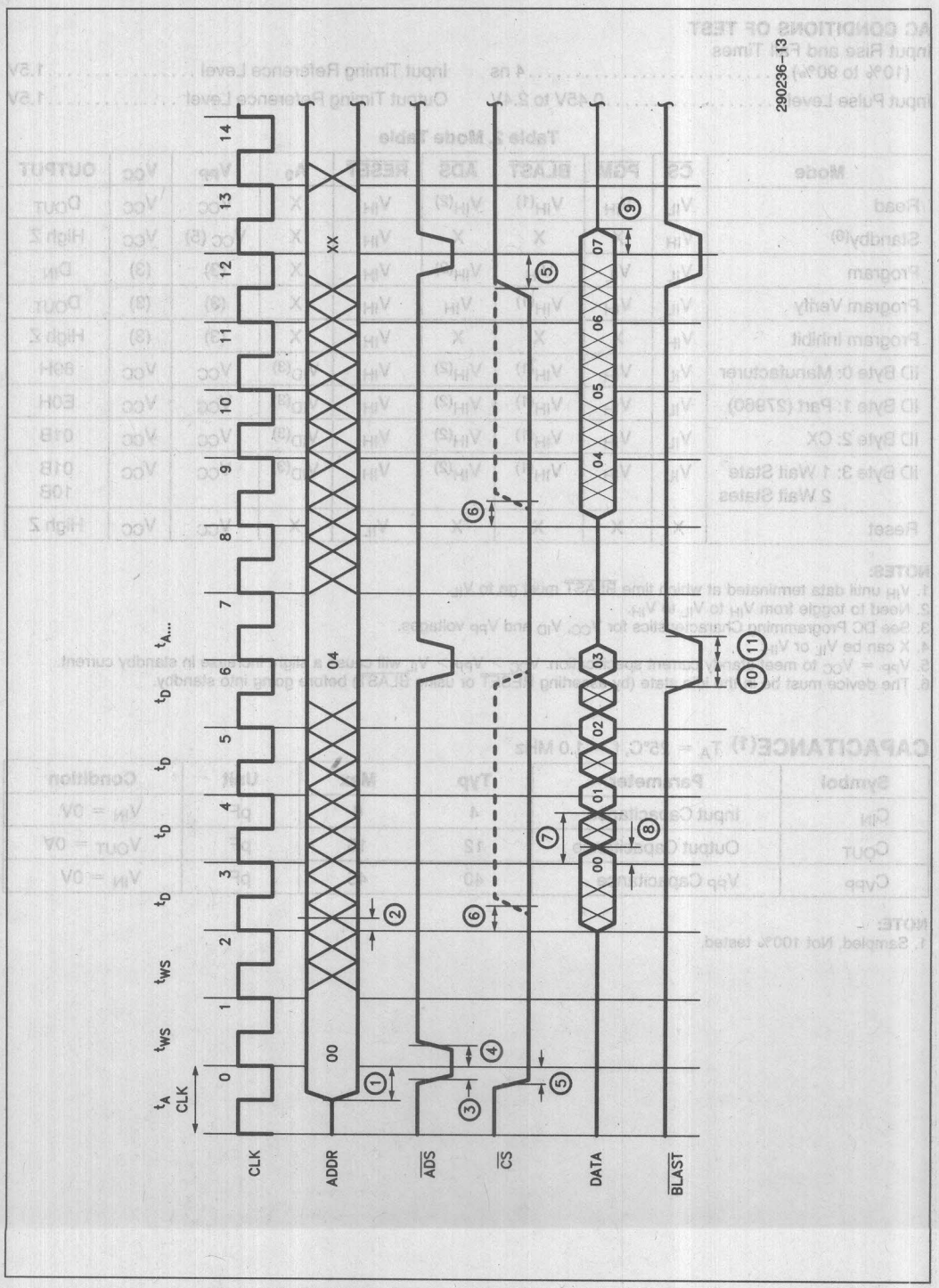


Figure 10. 27960CX Pipelined 2 Wait State AC Waveforms

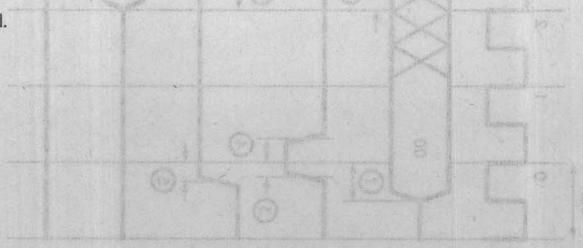
					V_{IH}	X	(3)	(3)	High Z
ID Byte 0: Manufacturer	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	89H
ID Byte 1: Part (27960)	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	E0H
ID Byte 2: CX	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	01B
ID Byte 3: 1 Wait State 2 Wait States	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	01B 10B
Reset	X	X	X	X	V_{IL}	X	V_{CC}	V_{CC}	High Z

NOTES:
1. V_{IH} until data terminated at which time $\overline{BLAST}$ must go to V_{IL}.
2. Need to toggle from V_{IH} to V_{IL} to V_{IH}.
3. See DC Programming Characteristics for V_{CC}, V_{ID} and V_{PP} voltages.
4. X can be V_{IL} or V_{IH}.
5. $V_{PP} = V_{CC}$ to meet standy current specification. $V_{CC} > V_{PP} > V_{IL}$ will cause a slight increase in standby current.
6. The device must be in the idle state (by asserting $\overline{RESET}$ or using $\overline{BLAST}$) before going into standby.

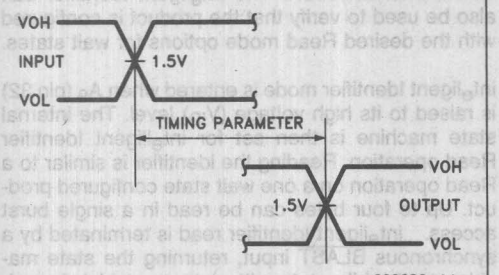
CAPACITANCE(1) $T_A = 25°C$, f = 1.0 MHz

Symbol	Parameter	Typ	Max	Unit	Condition
C_{IN}	Input Capacitance	4	6	pF	$V_{IN} = 0V$
C_{OUT}	Output Capacitance	12	15	pF	$V_{OUT} = 0V$
C_{VPP}	V_{PP} Capacitance	40	45	pF	$V_{IN} = 0V$

NOTE:
1. Sampled. Not 100% tested.

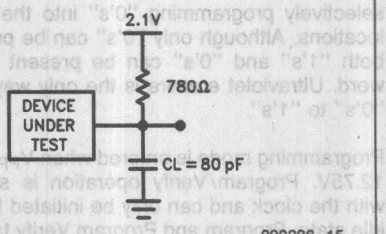


AC INPUT/OUTPUT REFERENCE WAVEFORMS



Input and output timings are measured from 1.5V. Timing values are specified assuming maximum input and output rise and fall time = 4 ns.

AC TESTING LOAD CIRCUIT

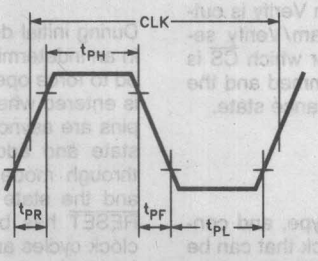


CL includes jig capacitance
For t_{CHQZ} C_L = 5 pF and R_L = 405Ω

CLOCK CHARACTERISTICS

Versions		33 MHz		25 MHz		20 MHz		16 MHz		Units
Symbol	Parameter	Min	Max	Min	Max	Min	Max	Min	Max	
CLK	Period	30.3		40		50		62.5		ns
t_{PR}	Rise Time	1	4	1	4	1	4	1	4	ns
t_{PF}	Fall Time	1	4	1	4	1	4	1	4	ns
t_{PL}	Low Time	(t/2) − 2	t/2	(t/2) − 3	t/2	(t/2) − 4	t/2	(t/2) − 4	t/2	ns
t_{PH}	High Time	(t/2) − 2	t/2	(t/2) − 3	t/2	(t/2) − 4	t/2	(t/2) − 4	t/2	ns
Max Rise Time for Programming CLK = 100 ns										

CLOCK WAVEFORM



Program/Program Verify

Initially, and after each erasure, all bits of the EPROM are in the "1's" state. Data is introduced by selectively programming "0's" into the desired bit locations. Although only "0's" can be programmed, both "1's" and "0's" can be present in the data word. Ultraviolet erasure is the only way to change "0's" to "1's".

Programming mode is entered when V_{PP} is raised to 12.75V. Program/Verify operation is synchronous with the clock and can only be initiated following an idle state. Program and Program Verify take place in 3 clock cycles. In the first clock cycle, addresses and data are input and programming occurs. Program Verify follows in the second clock cycle and the third clock cycle terminates synchronous Program/Verify operation, returning the state machine to the idle state with outputs at high impedance.

As in the Read mode, A_2–A_{16} point to a four byte block in the memory array. During programming, the internal address increment circuitry is disabled and the programmer must supply A_0 and A_1 to point to an individual byte within the four byte block that is to be programmed. Only one byte is programmed in each 3 cycle Program/Verify sequence.

Program Inhibit

The Program Inhibit mode allows parallel programming and verification of multiple devices with different data. With V_{PP} at 12.75V, a Program/Verify sequence is initiated for any device that receives a valid $\overline{ADS}$ pulse and rising clock edge while $\overline{CS}$ is asserted. A $\overline{PGM}$ pulse programs data in the first cycle of the sequence and data for Program Verify is output in the second cycle. The Program/Verify sequence is inhibited on any devices for which $\overline{CS}$ is not asserted. Data will not be programmed and the outputs will remain in their high impedance state.

inteligent Identifier™ Mode

The device's manufacturer, product type, and configuration are stored in a four byte block that can be accessed by using the inteligent Identifier™ mode.

The programmer can verify the device identifier and choose the programming algorithm that corresponds to the Intel 27960CX. The inteligent Identifier can also be used to verify that the product is configured with the desired Read mode options for wait states.

inteligent Identifier mode is entered when A_9 (pin 32) is raised to its high voltage (V_{ID}) level. The internal state machine is then set for inteligent Identifier Read operation. Reading the identifier is similar to a Read operation on a one wait state configured product. Up to four bytes can be read in a single burst access. inteligent Identifier read is terminated by a synchronous $\overline{BLAST}$ input, returning the state machine to the idle state with outputs at high impedance.

The four byte block code for the inteligent Identifier code is located at address 00H through 03H and is encoded as follows:

MEANING	(A1, A0)	DATA
Intel ID	Byte 00	89h
27960	Byte 01	E0h
CX	Byte 10	01b
1 Wait State	Byte 11	01b
2 Wait States	Byte 11	10b

RESET MODE

Due to the synchronous nature of the 27960CX, the various operating modes must be initiated from a known idle state. During normal operation, the internal state machine returns to an idle state at the termination of a bus access (after $\overline{BLAST}$ is asserted).

During initial device power up, the state machine is in an indeterminant state. The reset mode is provided to force operation into the idle state. Reset mode is entered when the $\overline{RESET}$ pin is asserted. Output pins are asynchronously set to the high impedance state and address latches are put into the flow through mode. A reset is successfully completed and the state machine set in an idle state when $\overline{RESET}$ has been asserted for a minimum of 10 clock cycles and deasserted for five clock cycles.

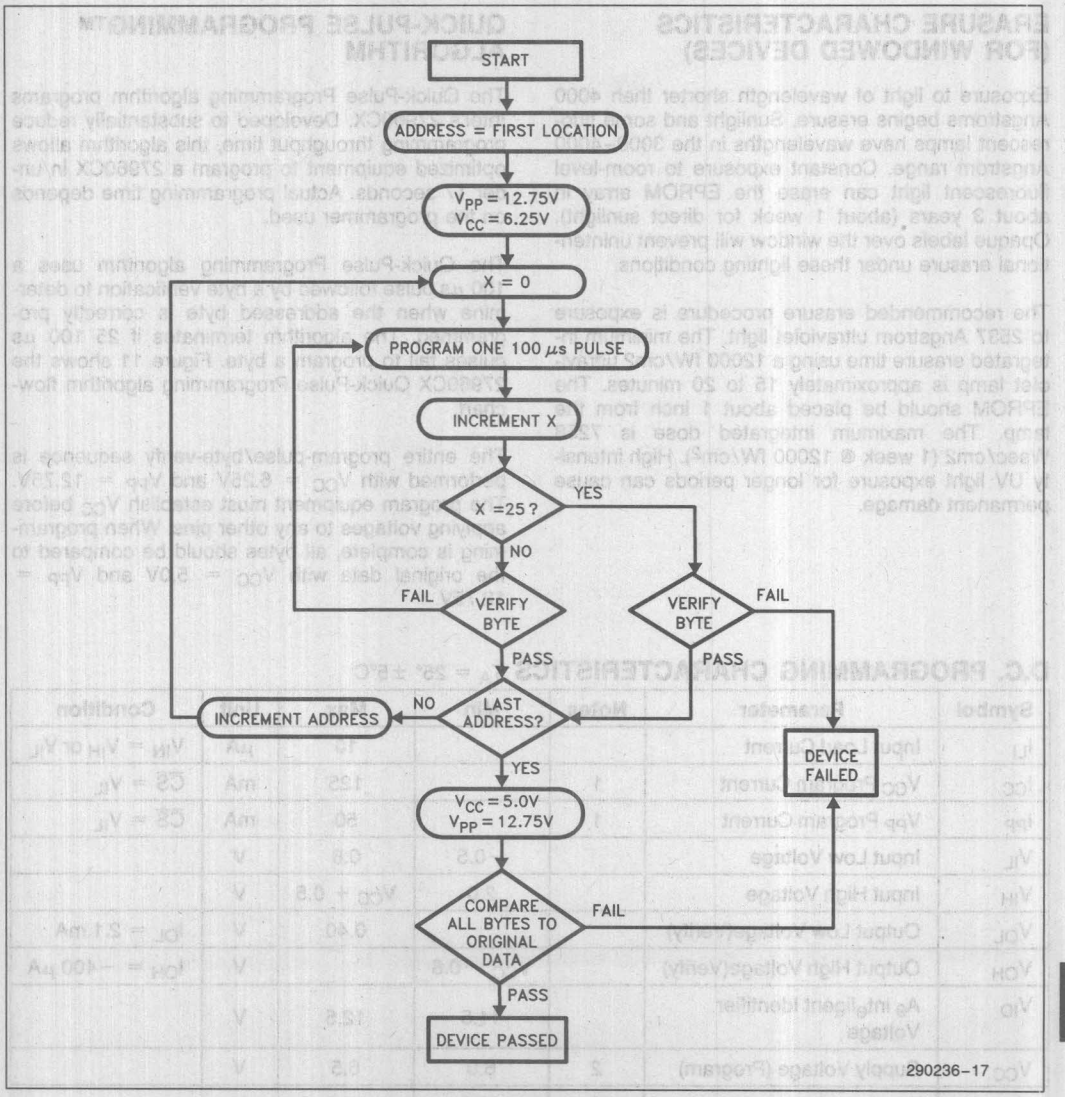


Figure 11. Quick-Pulse Programming™ Algorithm

ERASURE CHARACTERISTICS (FOR WINDOWED DEVICES)

Exposure to light of wavelength shorter than 4000 Angstroms begins erasure. Sunlight and some fluorescent lamps have wavelengths in the 3000–4000 Angstrom range. Constant exposure to room-level fluorescent light can erase the EPROM array in about 3 years (about 1 week for direct sunlight). Opaque labels over the window will prevent unintentional erasure under these lighting conditions.

The recommended erasure procedure is exposure to 2537 Angstrom ultraviolet light. The minimum integrated erasure time using a 12000 fW/cm2 ultraviolet lamp is approximately 15 to 20 minutes. The EPROM should be placed about 1 inch from the lamp. The maximum integrated dose is 7258 Wsec/cm2 (1 week @ 12000 fW/cm^2). High intensity UV light exposure for longer periods can cause permanent damage.

QUICK-PULSE PROGRAMMING™ ALGORITHM

The Quick-Pulse Programming algorithm programs Intel's 27960CX. Developed to substantially reduce programming throughput time, this algorithm allows optimized equipment to program a 27960CX in under 17 seconds. Actual programming time depends on the programmer used.

The Quick-Pulse Programming algorithm uses a 100 μs pulse followed by a byte verification to determine when the addressed byte is correctly programmed. The algorithm terminates if 25 100 μs pulses fail to program a byte. Figure 11 shows the 27960CX Quick-Pulse Programming algorithm flowchart.

The entire program-pulse/byte-verify sequence is performed with V_{CC} = 6.25V and V_{PP} = 12.75V. The program equipment must establish V_{CC} before applying voltages to any other pins. When programming is complete, all bytes should be compared to the original data with V_{CC} = 5.0V and V_{PP} = 12.75V.

D.C. PROGRAMMING CHARACTERISTICS $T_A = 25° \pm 5°C$

Symbol	Parameter	Notes	Min	Max	Unit	Condition
I_{LI}	Input Load Current			10	μA	$V_{IN} = V_{IH}$ or V_{IL}
I_{CC}	V_{CC} Program Current	1		125	mA	$\overline{CS} = V_{IL}$
I_{PP}	V_{PP} Program Current	1		50	mA	$\overline{CS} = V_{IL}$
V_{IL}	Input Low Voltage		−0.5	0.8	V	
V_{IH}	Input High Voltage		2.0	V_{CC} + 0.5	V	
V_{OL}	Output Low Voltage(Verify)			0.40	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage(Verify)		V_{CC} − 0.8		V	I_{OH} = −400 μA
V_{ID}	A9 intelligent Identifier Voltage		11.5	12.5	V	
V_{CC}	Supply Voltage (Program)	2	6.0	6.5	V	
V_{PP}	Program Voltage	2	12.5	13.0	V	

NOTES:
1. The maximium current value is with outputs unloaded.
2. V_{CC} must be applied simultaneously or before V_{PP} and removed simultaneously or after V_{PP}.
3. During programming clock levels are V_{IH} and V_{IL}.

A.C. PROGRAMMING, RESET AND ID CHARACTERISTICS $0°C < T_A < +70°C$

No.	Symbol	Parameter	Notes	Min	Max	Unit
1	t_{AVPL}	Address Valid to $\overline{PGM}$ Low		2		µs
2	t_{CHAX}	CLK High to Address Invalid		50		ns
3	t_{LLCH}	$\overline{ADS}$ Low to CLK High	1	50		ns
4	t_{CHLH}	CLK High to $\overline{ADS}$ High	2	50		ns
5	t_{SVCH}	$\overline{CS}$ Valid to CLK High		50		ns
6	t_{CHSX}	CLK High to $\overline{CS}$ Invalid	3			ns
7	t_{CHQV}	CLK High to D_{OUT} Valid		100		ns
8	t_{CHQX}	CLK High to D_{OUT} Invalid		0		ns
9	t_{BVCH}	$\overline{BLAST}$ Valid to CLK High		50		ns
10	t_{CHBX}	CLK High to $\overline{BLAST}$ Invalid	4	50		ns
11	t_{QVPL}	DATA Valid to $\overline{PGM}$ Low		2		µs
12	t_{PLPH}	$\overline{PGM}$ Program Pulse Width		95	105	µs
13	t_{PHQX}	$\overline{PGM}$ High to D_{IN} Invalid		2		µs
14	t_{CLPL}	CLK Low to $\overline{PGM}$ Low		50		ns
15	t_{QZCH}	D_{IN} Tri-State to CLK High		2		µs
16	t_{VCS}	V_{CC} Program Voltage to CLK High	7	2		µs
17	t_{VPS}	V_{PP} Program Voltage to CLK High	7	2		µs
18	t_{A_9HCH}	A_9 V_{ID} Voltage to CLK High		2		µs
19	t_{CHA_9X}	CLK High to A_9 Not V_{ID} Voltage		2		µs
20	t_{RVCH}	$\overline{RESET}$ Valid to CLK High	6	50		ns
21	t_{CHCL}	CLK High to CLK Low	5	100		ns
22	t_{CLCH}	CLK Low to CLK High	5	100		ns

NOTES:
1. If $\overline{CS}$ is low, $\overline{ADS}$ can go low no sooner than the falling edge of the previous CLK.
2. $\overline{ADS}$ must return high prior to the next rising edge of clock.
3. $\overline{CS}$ must remain low until after the rising edge of CLK1.
4. $\overline{BLAST}$ must return high prior to the next rising edge of CLK.
5. Max CLK rise/fall time is 100 ns.
6. $\overline{RESET}$ must be low for 10 clock cycles and high for 5 clock cycles.
7. V_{CC} must be applied simultaneously or before V_{PP} and removed simultaneously or after V_{PP}.

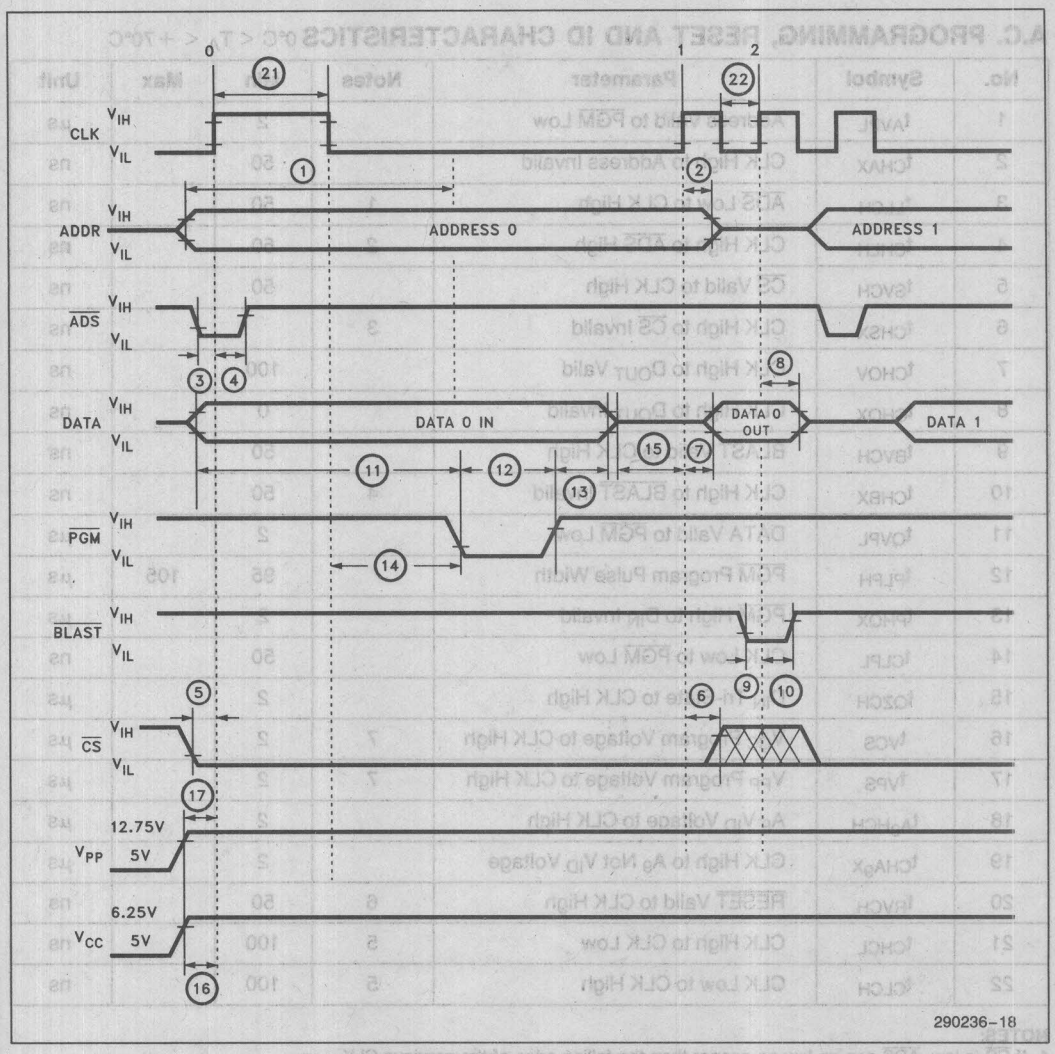


Figure 12. 27960CX Programming Waveforms

RESET and int$_e$ligent Identifier Waveforms

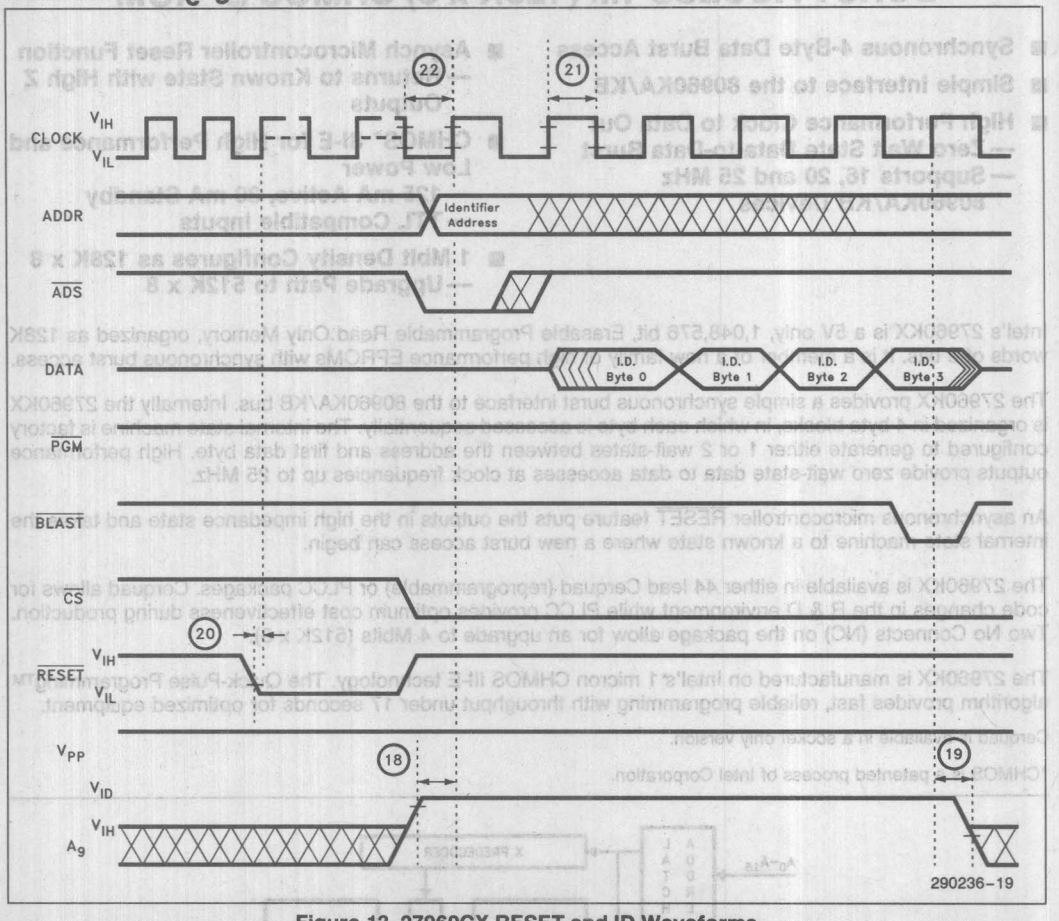


Figure 13. 27960CX RESET and ID Waveforms

7

27960KX
BURST ACCESS 1M (128K x 8) CHMOS EPROM

- **Synchronous 4-Byte Data Burst Access**
- **Simple Interface to the 80960KA/KB**
- **High Performance Clock to Data Out**
  - **— Zero Wait State Data-to-Data Burst**
  - **— Supports 16, 20 and 25 MHz 80960KA/KB Devices**
- **Asynch Microcontroller Reset Function**
  - **— Returns to Known State with High Z Outputs**
- **CHMOS* III-E for High Performance and Low Power**
  - **— 125 mA Active, 30 mA Standby**
  - **— TTL Compatible Inputs**
- **1 Mbit Density Configures as 128K x 8**
  - **— Upgrade Path to 512K x 8**

Intel's 27960KX is a 5V only, 1,048,576 bit, Erasable Programmable Read Only Memory, organized as 128K words of 8 bits. It is a member of a new family of high performance EPROMs with synchronous burst access.

The 27960KX provides a simple synchronous burst interface to the 80960KA/KB bus. Internally the 27960KX is organized in 4 byte blocks, in which each byte is accessed sequentially. The internal state machine is factory configured to generate either 1 or 2 wait-states between the address and first data byte. High performance outputs provide zero wait-state data to data accesses at clock frequencies up to 25 MHz.

An asynchronous microcontroller $\overline{\text{RESET}}$ feature puts the outputs in the high impedance state and takes the internal state machine to a known state where a new burst access can begin.

The 27960KX is available in either 44 lead Cerquad (reprogrammable) or PLCC packages. Cerquad allows for code changes in the R & D environment while PLCC provides optimum cost effectiveness during production. Two No Connects (NC) on the package allow for an upgrade to 4 Mbits (512K x 8).

The 27960KX is manufactured on Intel's 1 micron CHMOS III-E technology. The Quick-Pulse Programming™ algorithm provides fast, reliable programming with throughput under 17 seconds for optimized equipment.

Cerquad is available in a socket only version.

*CHMOS is a patented process of Intel Corporation.

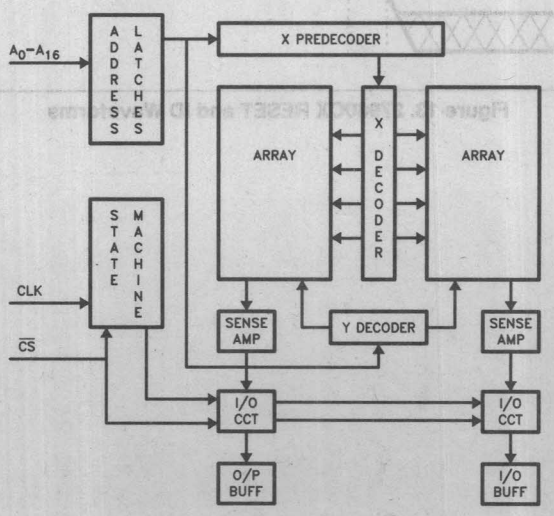


Figure 1. 27960KX Burst EPROM Block Diagram

October 1990
Order Number: 290237-004

27960KX BURST EPROM

EPROMs are established as the preferred code storage device in embedded applications. The non-volatile, flexible, reliable, cost effective EPROM makes a product easier to design, manufacture and service. Until recently, however, EPROMs could not match the performance needs of high-end systems. The 27960KX was designed to support the 80960KA/KB embedded processor. It utilizes the burst interface to offer near zero-wait state performance without the high cost normally associated with this performance.

In embedded designs, board space and cost must be kept at a minimum without impacting performance and reliability. The 27960KX removes the need for expensive high-speed shadow RAM backed up by slow EPROM or ROM for non-volatile code storage. Code optimization concerns are reduced with "off-chip" code fetches no longer crippling to system performance. FONTs can be run directly out of these EPROMs at the same performance as high-speed DRAMs. With the 27960KX, the EPROM is the ideal code or FONT storage device for your 80960KA/KB system.

Architecture

The 27960KX provides a simple, synchronous burst interface to the 80960KA/KB's bus. Internally, the 27960KX is organized in 4 byte blocks each byte is accessed sequentially. A burst access begins on the first clock pulse after $\overline{CS}$ is asserted. The address of the four byte block is latched by the rising edge of $\overline{ALE}$. After a preset number of wait-states (1 or 2), data is output one byte at a time on each subsequent clock cycle. A burst access is terminated on the rising edge of CLOCK if $\overline{BLAST}$ is asserted. High performance outputs provide zero wait-state data to data accesses at clock frequencies up to 25 MHz. Extra power and ground pins dedicated to the outputs reduce the effects of fast output switching on device performance.

The 27960KX delivers 4 bytes of data in 8 clock cycles at 25 MHz and 4 bytes of data in 7 clock cycles at 20 MHz. In a 32-bit configuration, this translates into a read bandwidth of 50 Mbytes/sec and 45 Mbytes/sec respectively. Performance capability of the 27960KX in different 80960KA/KB systems is given in Table 1.

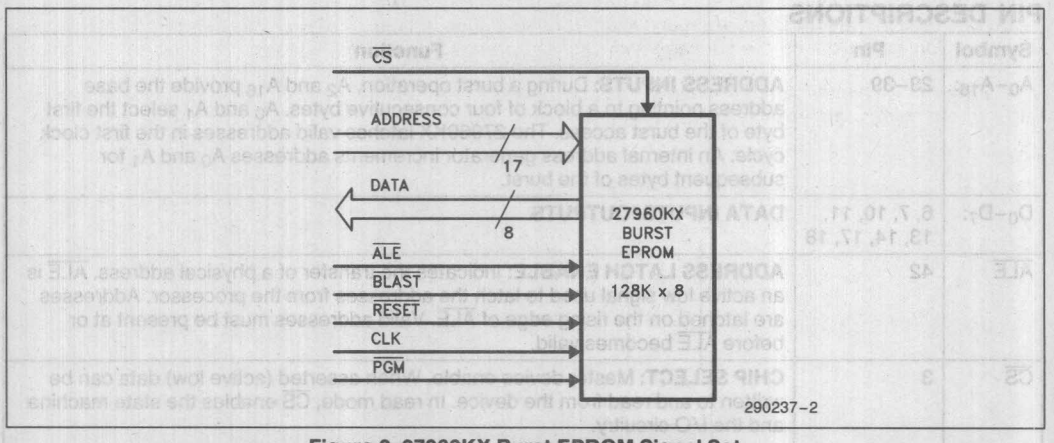


Figure 2. 27960KX Burst EPROM Signal Set

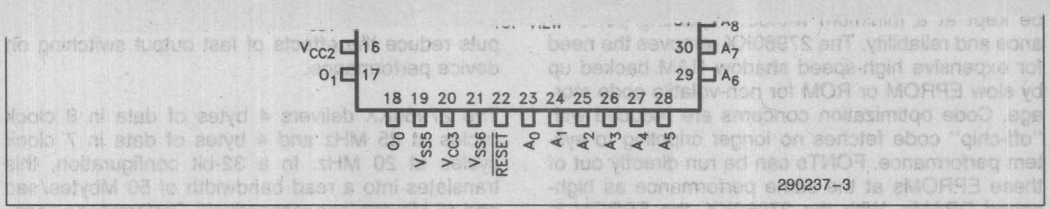


Figure 3. 27960KX 44-Lead PLCC/CERQUAD Pinout

PIN DESCRIPTIONS

Symbol	Pin	Function
A_0–A_{16}:	23–39	**ADDRESS INPUTS:** During a burst operation, A_2 and A_{16} provide the base address pointing to a block of four consecutive bytes. A_0 and A_1 select the first byte of the burst access. The 27960KX latches valid addresses in the first clock cycle. An internal address generator increments addresses A_0 and A_1 for subsequent bytes of the burst.
D_0–D_7:	6, 7, 10, 11, 13, 14, 17, 18	**DATA INPUTS/OUTPUTS**
$\overline{ALE}$	42	**ADDRESS LATCH ENABLE:** Indicates the transfer of a physical address. $\overline{ALE}$ is an active low signal used to latch the addresses from the processor. Addresses are latched on the rising edge of $\overline{ALE}$. Valid addresses must be present at or before $\overline{ALE}$ becomes valid.
$\overline{CS}$	3	**CHIP SELECT:** Master device enable. When asserted (active low) data can be written to and read from the device. In read mode, $\overline{CS}$ enables the state machine and the I/O circuitry. **NOTES:** 1. The address decode path is independent of $\overline{CS}$, i.e., X and Y decoding is always powered up. 2. For programming, $\overline{CS}$ should remain low for the entire cycle. Program and verify functions are done one byte at a time. 3. $\overline{CS}$ going high does not terminate a concurrent burst cycle. 4. $\overline{CS}$ must be deasserted between bursts.
$\overline{BLAST}$	1	**BURST LAST:** Terminates a concurrent burst data cycle at the rising edge of the CLK. It must be asserted by the fourth data byte.
$\overline{RESET}$	22	**ASYNCHRONOUS RESET INPUT:** Resets the state machine into a known state, tri-states the outputs and puts address latches into the flow through mode. The duration of $\overline{RESET}$ should be 10 CLK cycles minimum. At least 5 clock cycles are required after deassertion of $\overline{RESET}$ before beginning the next cycle. Reset will abort a concurrent bus cycle.

PIN DESCRIPTIONS (Continued)

Symbol	Pin	Function
$\overline{PGM}$	43	**PROGRAM-PULSE CONTROL INPUT**
V_{PP}	2	**PROGRAMMING POWER SUPPLY V_{PP}**
V_{SS}	5, 8, 12, 15, 19, 21	**GROUND**
V_{CC}	9, 16, 20, 44	**SUPPLY VOLTAGE INPUT**

Table 1. Performance Capability

25/20 MHz 2 WS NON-BUFFERED : 4 WORDS/8 CLOCK CYCLES → 50/40 MBYTES/SEC

ADDR	A_{00}	WS	WS	-	-	-	-	RS	A_{01}	WS	WS	-	-	-	-	RS	
DATA	-	-	-	D_{00}	D_{01}	D_{02}	D_{03}	-	-	-	-	D_{10}	D_{11}	D_{12}	D_{13}		
CLK	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	

20 MHz 1 WS NON-BUFFERED : 4 WORDS/7 CLOCK CYCLES → 45 MBYTES/SEC

ADDR	A_{00}	WS	-	-	-	-	RS	A_{01}	WS	-	-	-	-	RS	A_{03}	WS
DATA	-	-	D_{00}	D_{01}	D_{02}	D_{03}	-	-	-	D_{10}	D_{11}	D_{12}	D_{13}			
CLK	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_1	C_2	C_3	C_4	C_5	C_6	C_7		

16 MHz 1 WS BUFFERED : 4 WORDS/7 CLOCK CYCLES → 36 MBYTES/SEC

ADDR	A_{00}	WS	-	-	-	-	RS	A_{01}	WS	-	-	-	-	RS	A_{03}	WS
DATA	-	-	D_{00}	D_{01}	D_{02}	D_{03}	-	-	-	D_{10}	D_{11}	D_{12}	D_{13}			
CLK	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_1	C_2	C_3	C_4	C_5	C_6	C_7		

INTERFACE EXAMPLE

Overview

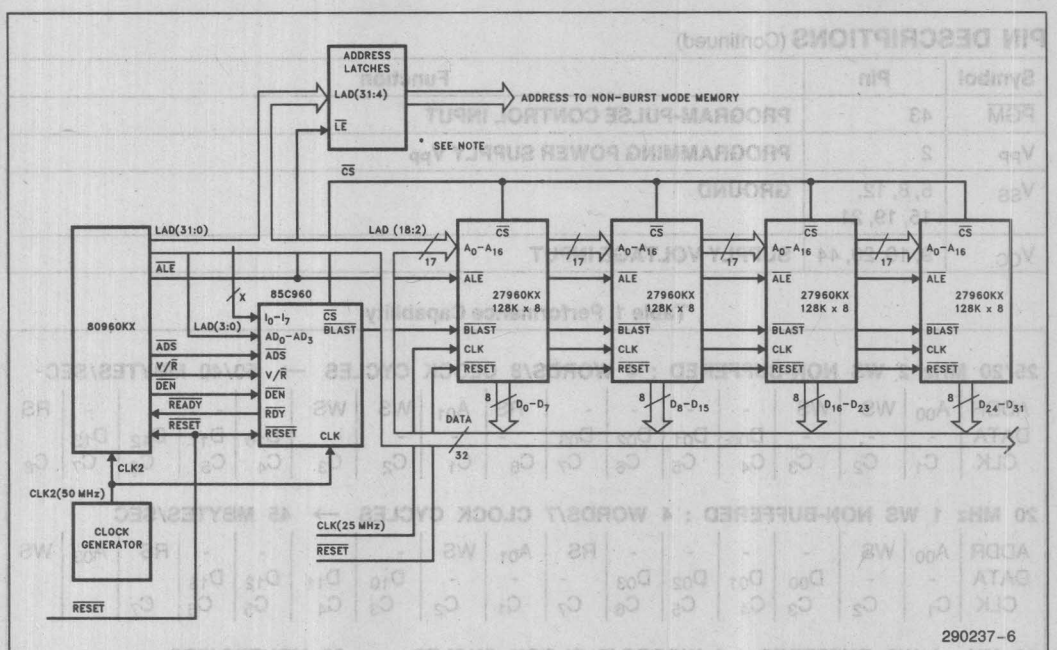
The following design offers a simple interface to the 80960KA/KB's bus.

A non-buffered 27960KX burst EPROM system is shown in Figure 4. Since the 27960KX is capable of driving a 120 pF load, large, non-buffered systems can be implemented by stacking up to 2 banks of 4 EPROMs, giving a memory size of 256K x 32. The input capacitive load seen on the address lines (due to the EPROM only) is 24 pF for a 128K x 32 system (shown) and 48 pF for a 256K x 32 system. The EPROM is specified at 4 pF for input capacitance and 12 pF typical for output capacitance. Larger systems can be implemented with buffers.

Chip Select Logic

High order address lines are decoded to provide $\overline{CS}$. Qualification with other signals is not required. The chip select logic can be implemented with standard asynchronous decoders, PAL's or PLD's (like Intel's 85C960).

7



NOTE:
27960KX does not require address latches

Figure 4. 128K x 32 Burst EPROM System

Waveforms

Figure 5 shows the timing waveforms of 27960KX reads in a 32-bit system.

$\overline{CS}$ setup time

$\overline{CS}$ setup time is the time between $\overline{CS}$ asserted and the first rising CLK edge of CLK (during the address cycle). Since a memory access begins on the first CLK rising edge after $\overline{CS}$ asserted, a minimum $\overline{CS}$ setup time of 5 ns (t_{SVCH}) at 25 MHz is required. With the 80960KA/KB's maximum valid address delay of 18 ns at 25 MHz, 13 ns remains for $\overline{CS}$ decoding logic.

$\overline{CS}$ Deassert between bursts

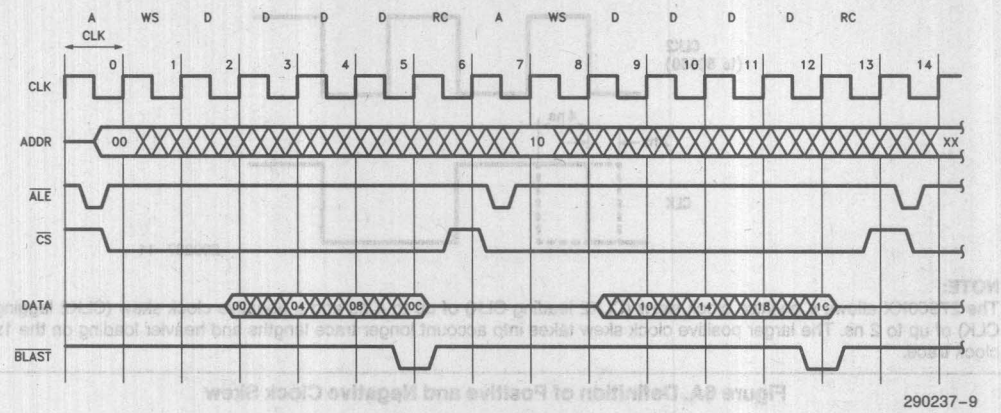
After every EPROM read (one to four words) $\overline{CS}$ must be deasserted.

Reset and $\overline{RESET}$

The 27960KX uses $\overline{RESET}$. The 80960 KA/KB RESET signal must be inverted for the 27960KX.

Clock Phase

The initial rising edge of CLK and CLK2 must be in phase with as small a skew as possible.



NOTES:
1. 1-0-0-0 Burst Read → 1 indicates the number of wait states to access the first word
   0's indicate the number of wait states for subsequent data words (0 in this case)
2. 27960KX latches addresses on the rising edge of ALE: it has an internal address generator which increments addresses for subsequent words of the burst.

Figure 5. Two Cycles of a 27960KX 1 Wait State, 4-Byte Read (1-0-0-0 Burst Read) in a 32-Bit System

27960KX DEVICE NAMES

The device names on the 27960KX were derived as mnemonics that correspond to the number of wait states and expected operating frequency for the device. For example, the 25 MHz, 2 wait state 27960KX is named 27960K2-25.

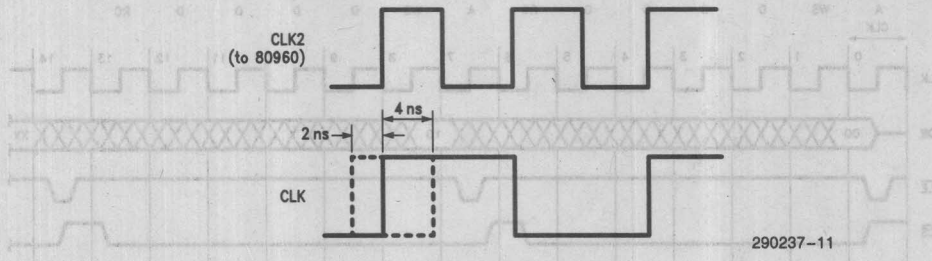
AC TIMING DERIVATIONS

The AC timings for the 27960KX were generated specifically to meet the requirements of the 80960KA/KB microprocessor. In each case the applicable 80960KA/KB clock frequency and AC timing were taken together with an address buffer delay (if needed) and a 4 ns positive clock skew or a 2 ns negative clock skew (see Figure 6A) guardband to generate the 27960KX AC timing. Examples of clock generation circuits (like Figures 6B and 6C) with detailed analysis and PAL equations will be made available in a separate Applications note. Worst case timings were always assumed. The example below shows how the 27960K1-20 $tavc_0h$ timing was derived.

@20 MHz the clock cycle is ~50 ns.
t_6 of the 80960KA/KB is 2–20 ns.
4 ns clock skew guardband.

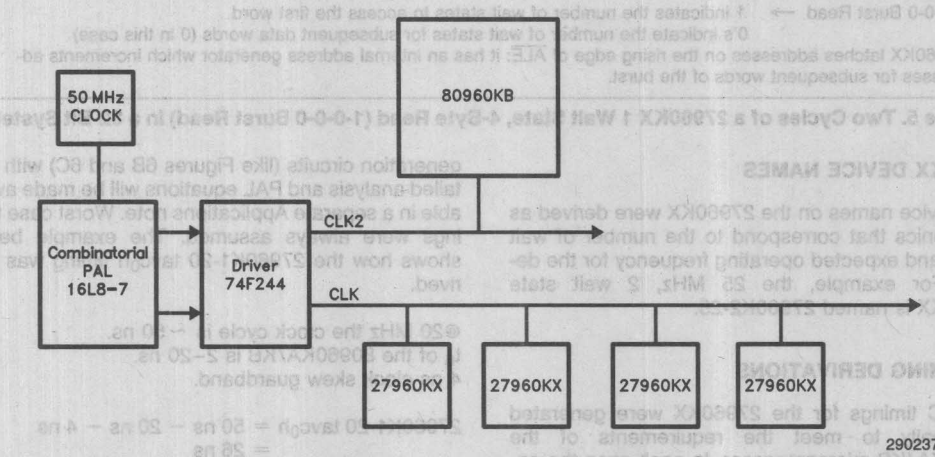
$$\text{27960K1-20 } tavc_0h = 50\text{ ns} - 20\text{ ns} - 4\text{ ns} = 26\text{ ns}$$

On timings such as this, where the EPROM is faster than the microprocessor, we specified the EPROM's timing leaving the excess time as system guardband.



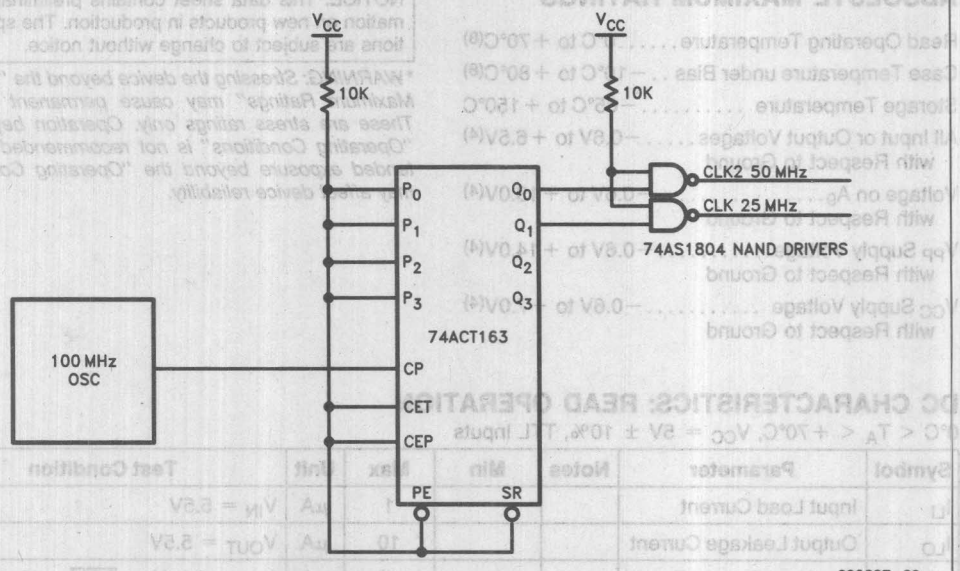
NOTE:
The 27960KX allows a positive clock skew (CLK2 leading CLK) of up to 4 ns and a negative clock skew (CLK2 lagging CLK) of up to 2 ns. The larger positive clock skew takes into account longer trace lengths and heavier loading on the 1x clock trace.

Figure 6A. Definition of Positive and Negative Clock Skew



NOTE:
CLK and CLK2 are generated by the same PAL. This minimizes skew between CLK and CLK2. Both PAL outputs are fed to a 74F244 driver. The EPROMs should be as close to the clock driver as possible.

Figure 6B. Example Clock Circuit with Minimum Skew



NOTE:
This clock generation circuit uses a 100 MHz oscillator. The EPROMs should be as close to the NAND drivers as possible.

Figure 6C. Example Clock Circuit Using a 100 MHz Oscillator

Decoders are needed for the systems address (chip select) decoding. For the 27960KX's timings we assumed a 5–10 ns chip select decoder for 16 MHz and 20 MHz frequencies and a 5–9 ns decoder for 25 MHz systems. The example below shows how the 27960K2-25 tsvch timing was derived.

@25 MHz the clock cycle is ~40 ns.
t_6 of the 80960KA/KB is 2–18 ns.
Decoder = 9 ns
4 ns clock skew guardband

27960K2-25 tsvch = 40 ns − 18 ns − 9 ns − 4 ns
= 9 ns

SYSTEM BUFFERING CONSIDERATIONS

For many large system applications buffering may be required between the microprocessor and memory devices. The 20 MHz − 2 WS and 16 MHz 27960KX AC timings take this into account. For applications at these frequencies not requiring buffering these devices will provide an additional 5–10 ns of system guardband.

The list below shows the buffers used in generating these timings:

	Input Buffer	Output Buffer
20 MHz	9 ns	5 ns
16 MHz	10 ns	7 ns

The 20 MHz buffers are slightly faster in keeping with the increased sensitivity for higher performance. We chose the above buffers because of their wide availability. Significantly faster buffers are available for applications requiring them. The example below shows tchqv for the 27960K2-20.

@20 MHz the clock cycle is ~50 ns.
t_{10} of the 80960KA/KB is 3 ns.
Output buffer for 20 MHz = 7 ns.
4 ns clock skew guardband

27960K2-20 tchqv = 50 ns − 7 ns − 3 ns − 4 ns
= 36 ns

ABSOLUTE MAXIMUM RATINGS*

Read Operating Temperature . . . . . 0°C to +70°C(8)

Case Temperature under Bias . . −10°C to +80°C(8)

Storage Temperature . . . . . −65°C to +150°C

All Input or Output Voltages . . . . . −0.6V to +6.5V(4) with Respect to Ground

Voltage on A_9 . . . . . −0.6V to +13.0V(4) with Respect to Ground

V_{PP} Supply Voltage . . . . . −0.6V to +14.0V(4) with Respect to Ground

V_{CC} Supply Voltage . . . . . −0.6V to +7.0V(4) with Respect to Ground

NOTICE: This data sheet contains preliminary information on new products in production. The specifications are subject to change without notice.

**WARNING: Stressing the device beyond the "Absolute Maximum Ratings" may cause permanent damage. These are stress ratings only. Operation beyond the "Operating Conditions" is not recommended and extended exposure beyond the "Operating Conditions" may affect device reliability.*

DC CHARACTERISTICS: READ OPERATION

0°C < T_A < +70°C, V_{CC} = 5V ± 10%, TTL Inputs

Symbol	Parameter		Notes	Min	Max	Unit	Test Condition
I_{LI}	Input Load Current				1	μA	V_{IN} = 5.5V
I_{LO}	Output Leakage Current				10	μA	V_{OUT} = 5.5V
I_{PP}	V_{PP} Load Current Read				10	μA	V_{PP} = 0 to V_{CC}, $\overline{PGM}$ = V_{IH}
I_{SB}	V_{CC} Standby	Switching	2		45	mA	$\overline{CS}$ = V_{IH}, f = 25 MHz
		Stable	2		30	mA	$\overline{CS}$ = V_{IH}
I_{CC}	V_{CC} Active Current		1, 3, 7		125	mA	$\overline{CS}$ = V_{IL}, f = 25 MHz, I_{OUT} = 0 mA
V_{IL}	Input Low Voltage		4	−0.5	0.8	V	
V_{IH}	Input High Voltage			2.0	V_{CC}+1	V	
V_{OL}	Output Low Voltage				0.45	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage		5	V_{CC}−0.8		V	I_{OH} = −100 μA
			5	2.4		V	I_{OH} = −400 μA
I_{OS}	Output Short Circuit		6		100	mA	

NOTES:

1. Maximum current is with outputs unloaded.
2. I_{CC} standby current assumes no output loading, i.e., I_{OH} = I_{OL} = 0 mA.
3. I_{CC} is the sum of current through V_{CC3} + V_{CC4} and does not include the current through V_{CC1} and V_{CC2}. (V_{CC1} and V_{CC2} supply power to the output drivers. V_{CC3} and V_{CC4} supply power to the rest of the device.)
4. Minimum DC voltage on input and output pins is −0.5V. During transitions, this level may undershoot to −2.0V for periods less than 20 ns.
5. Maximum DC voltage on input and output pins is V_{CC} + 0.5V which may overshoot to V_{CC} + 2.0V for periods less than 20 ns.
6. One output shorted for no more than one second. I_{OS} is sampled but not 100% tested.
7. I_{CC} max measured with a 0.11 μF capacitor between V_{CC} and V_{SS}.
8. This specification defines commercial product operating temperatures.

EXPLANATION OF AC SYMBOLS

The nomenclature used for timing parameters are as per IEEE STD 662-1980 IEEE Standard Terminology for Semiconductor Memory.

Each timing symbol has five characters. The first is always a "t" (for time). The second character represents a signal name, e.g., (CLK, $\overline{ALE}$, etc.). The third character represents the signal's level (high or low) for the signal indicated by the second character. The fourth character represents a signal name at which a transition occurs marking the end of the time interval being specified.

The fifth character represents the signal level indicated for the fourth character. The list below shows character representations.

A:	Address	R:	$\overline{Reset}$
B:	$\overline{BLAST}$	Q:	Data
C:	Clock	S:	$\overline{CS}$
H:	Logic High Level	t:	Time
L:	$\overline{ALE}$/Logic Low Level	V:	Valid
P:	V_{PP} Programming Voltage	Z:	Tri-state level
X:	No longer a valid "driven" logic level		

AC CHARACTERISTICS: READ OPERATION $0\,°C < T_A < +70°C, V_{CC} = 5V \pm 10\%$

Versions				27960K2-25		27960K1-20		27960K2-20		27960K1-16		Unit
				25 MHz 2 Wait States		20 MHz 1 Wait State		20 MHz 2 Wait States		16 MHz 1 Wait State		
No	Symbol	Characteristic	Notes	Min	Max	Min	Max	Min	Max	Min	Max	
1	t_{AVC_0H}	Address Valid to CLK High	CLK 0	12		18		10		15		ns
2	t_{AVLH}	Address Valid to $\overline{ALE}$ High		10		10		10		10		ns
3	t_{LLLH}	$\overline{ALE}$ Low to $\overline{ALE}$ High		12		12		12		12		ns
4	t_{LHAX}	$\overline{ALE}$ High to Address Invalid		8		8		8		8		ns
5	t_{SVCH}	$\overline{CS}$ Valid to CLK High	1, 5	5		8		7		8		ns
6	t_{C_NHSX}	CLK High to $\overline{CS}$ Invalid	2	0		0		0		0		ns
7	t_{CHQV}	CLK High to Data Valid	7		33		43		38		45	ns
8	t_{CHQX}	CLK High to Data Invalid		7		7		7		7		ns
9	t_{CHQZ}	CLK High to Data High-Z	6		30		35		35		35	ns
10	t_{BVCH}	$\overline{BLAST}$ Valid to CLK High		15		15		15		15		ns
11	t_{CHBX}	CLK High to $\overline{BLAST}$ Invalid	3	5	35	5	45	5	45	5	45	ns

NOTES:
1. Valid signal level is meant to be either a logic high or logic low.
2. t_{C_NHSX}—The subscript N represents the number of wait states for this parameter. $\overline{CS}$ can be de-asserted (high) after the number of wait states (N) has expired. The EPROM will continue to burst out data for the current cycle.
3. $\overline{BLAST}$ must be returned high before the next rising clock edge.
4. The sum of t_{CHQV} + t_{AVCH} + NCLK will not equal actual t_{AVQV} if independent test conditions are used to obtain t_{AVCH} and t_{CHQV} (N = number of wait states).
5. $\overline{CS}$ must be deasserted after every burst read (see Figure 7).
6. Sampled, not 100% tested. The transition is measured ±500 mV from steady state voltage.
7. For capacitive loads above 120 pF, t_{CHQV} can be derated by 1 ns/20 pF.

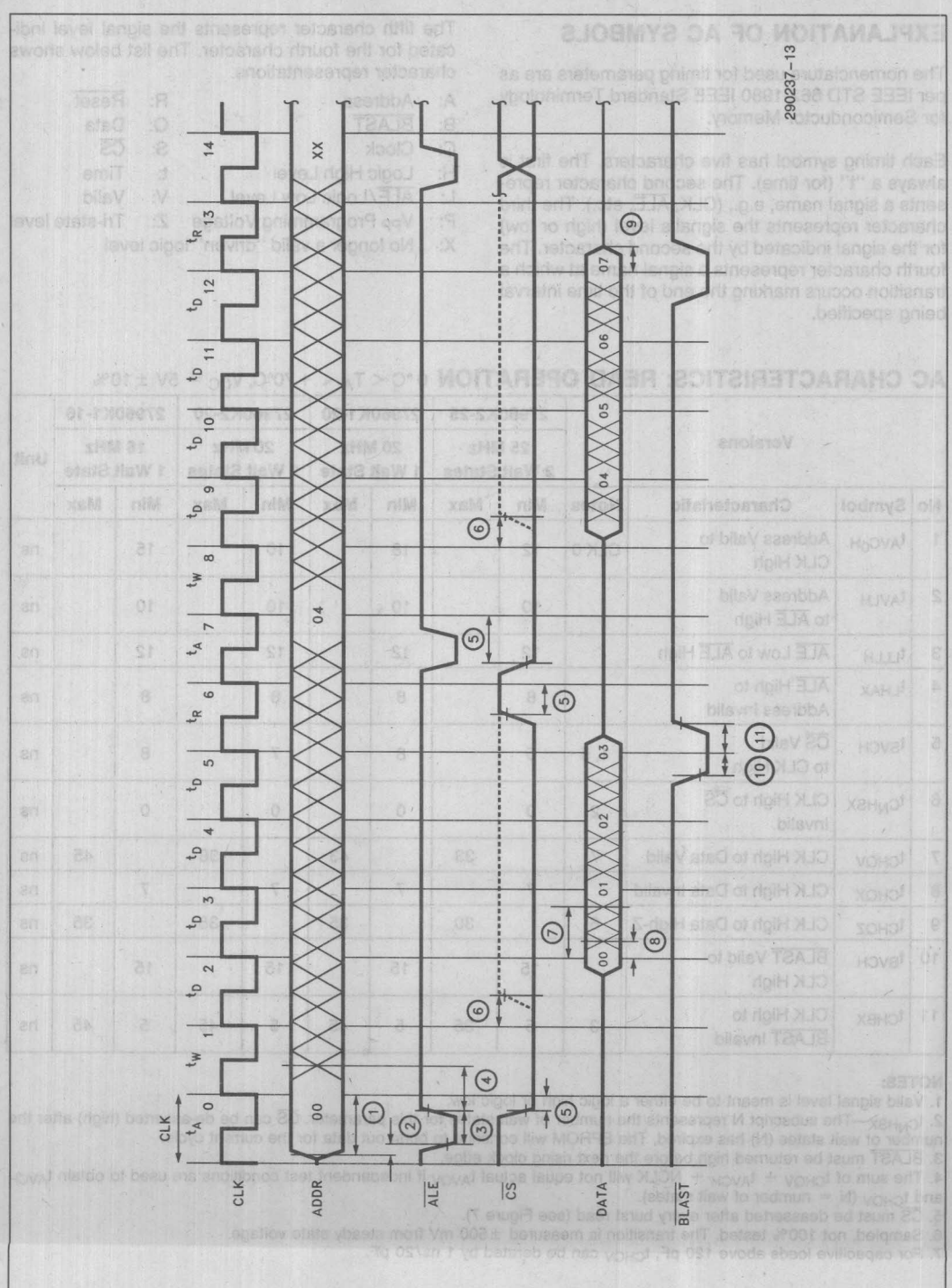


Figure 7. 27960KX 1 WS AC Read Waveforms

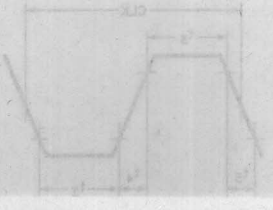
AC CONDITIONS OF TEST

Input Rise and Fall Times (10% to 90%) ..... 4 ns
Input Pulse Levels ..... 0.45V to 2.4V
Input Timing Reference Level 1.5V
Output Timing Reference Level ..... 0.8V and 2.0V

Table 2. Mode Table

MODE	$\overline{CS}$	$\overline{PGM}$	$\overline{BLAST}$	$\overline{ALE}$	$\overline{RESET}$	A_9	V_{PP}	V_{CC}	OUTPUT
Read	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	X(4)	V_{CC}	V_{CC}	D_{OUT}
Standby (6)	V_{IH}	X	X	X	V_{IH}	X	V_{CC}(5)	V_{CC}	High Z
Program	V_{IL}	V_{IL}	V_{IH}	V_{IH}(2)	V_{IH}	X	(3)	(3)	D_{IN}
Program Verify	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}	V_{IH}	X	(3)	(3)	D_{OUT}
Program Inhibit	V_{IH}	X	X	X	V_{IH}	X	(3)	(3)	High Z
ID Byte 0: Manufacturer	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	89H
ID Byte 1: Part (27960)	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	E0H
ID Byte 2: KX	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	00B
ID Byte 3: 1 Wait-State 2 Wait-States	V_{IL}	V_{IH}	V_{IH}(1)	V_{IH}(2)	V_{IH}	V_{ID}(3)	V_{CC}	V_{CC}	01B 10B
Reset	X	X	X	X	V_{IL}	X	V_{CC}	V_{CC}	High Z

NOTES:
1. V_{IH} until data terminated at which time $\overline{BLAST}$ must go to V_{IL}.
2. Need to toggle from V_{IH} to V_{IL} to V_{IH} to latch address.
3. See DC Programming Characteristics for V_{CC}, V_{ID} and V_{PP} voltages.
4. X can be V_{IL} or V_{IH}.
5. $V_{PP} = V_{CC}$ to meet standby current specification. $V_{CC} > V_{PP} > V_{IL}$ will cause a slight increase in standby current.
6. The device must be in the idle state (by asserting $\overline{RESET}$ or using $\overline{BLAST}$) before going into standby.

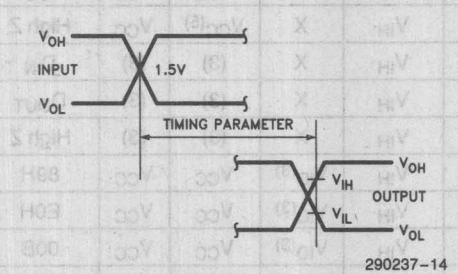


CAPACITANCE(1) $T_A = 25°C, f = 1.0$ MHz

Symbol	Parameter	Typ	Max	Unit	Condition
C_{IN}	Input Capacitance	4	6	pF	$V_{IN} = 0V$
C_{OUT}	Output Capacitance	12	15	pF	$V_{OUT} = 0V$
C_{VPP}	V_{PP} Capacitance	40	45	pF	$V_{IN} = 0V$

NOTE:
1. Sampled, not 100% tested

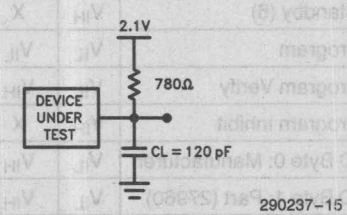
AC INPUT/OUTPUT REFERENCE WAVEFORMS



290237-14

AC test inputs are driven at 2.4V (V_{OH}) for a logic '1' and 0.45V (V_{OL}) for a logic '0'.
Input timing begins at 1.5V.
Output timing ends at V_{IH} (2.0V) and V_{IL} (0.8V)
Input Rise and fall times (10% to 90%) < 4.0 ns

AC TESTING LOAD CIRCUIT



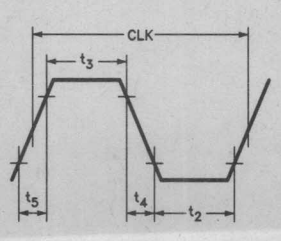
290237-15

For t_{CHQZ} C_L = 5 pF and R_L = 405Ω
C_L includes jig capacitance

CLOCK CHARACTERISTICS

Versions		25 MHz		20 MHz		16 MHz		Units
Symbol	Parameter	Min	Max	Min	Max	Min	Max	
CLK	Period	40		50		62.5		ns
T_5	Rise Time		10		10		10	ns
T_4	Fall Time		10		10		10	ns
T_2	Low Time	7		8		11		ns
T_3	High Time	7		8		11		ns
Max CLK Rise Time during Programming is 100 ns								

CLOCK WAVEFORM



290237-16

Program/Program Verify

Initially, and after each erasure, all bits of the EPROM are in the "1's" state. Data is introduced by selectively programming "0's" into the desired bit locations. Although only "0's" can be programmed, both "1's" and "0's" can be present in the data word. Ultraviolet erasure is the only way to change "0's" to "1's".

Program mode is entered when V_{PP} is raised to 12.75V. Program/Verify operation is synchronous with the clock and can only be initiated following an idle state. Program and Program Verify take place in 3 clock cycles. In the first clock cycle, addresses and data are input and programming occurs. Program Verify follows in the second clock cycle and the third clock cycle terminates synchronous Program/Verify operation, returning the state machine to the idle state with outputs at high impedance.

As in the Read mode, A_2–A_{16} point to a four byte block in the memory array. During Programming the internal address increment circuitry is disabled and the programmer must supply A_0 and A_1 to point to an individual byte within the four byte block that is to be programmed. Only one byte is programmed in each 3 cycle program/Verify sequence.

Program Inhibit

Program Inhibit mode allows parallel programming and verification of multiple devices with different data. With V_{PP} at 12.75V, a Program/Verify sequence is initiated for any device that receives a valid $\overline{ALE}$ pulse and rising clock edge while $\overline{CS}$ is asserted. A $\overline{PGM}$ pulse programs data in the first cycle of the sequence and data for Program Verify is output in the second cycle. The Program/Verify sequence is inhibited on any devices for which $\overline{CS}$ is not asserted during the first ($\overline{ALE}$) cycle. Data will not be programmed and the outputs will remain in their high impedance state.

inteligent Identifier™ Mode

The device's manufacturer, product type, and configuration are stored in a four byte block that can be accessed by using the inteligent Identifier™ mode. The programmer can verify the device identifier and choose the programming algorithm that corresponds to the Intel 27960KX. The inteligent Identifier can also be used to verify that the product is configured with the desired Read mode options for wait states.

Inteligent Identifier mode is entered when A_9 (pin 32) is raised to its high voltage (V_H) level. The internal state machine is then set for inteligent Identifier Read operation. Reading the Identifier is similar to a Read operation on a one wait state configured product. Up to four bytes can be read in a single burst access. inteligent Identifier read is terminated by a synchronous $\overline{BLAST}$ input, returning the state machine to the idle state with outputs at high impedance.

The four byte block code for the inteligent Identifier code is located at address 00H through 03H and is encoded as follows:

MEANING	(A_1, A_0)	DATA
Intel ID	Byte 00	89h
27960	Byte 01	E0h
KX	Byte 10	00b
1 wait state	Byte 11	01b
2 wait states	Byte 11	10b

RESET MODE

Due to the synchronous nature of the 27960KX, the various operating modes must be initiated from a known idle state. During normal operation, the internal state machine returns to an idle state at the termination of a bus access (after $\overline{BLAST}$ is asserted).

During initial device power up, the state machine is in an indeterminant state. The reset mode is provided to force operation in to the idle state. Reset mode is entered when the $\overline{RESET}$ pin is asserted. Output pins are asynchronously set to the high impedance state and address latches are put into the flow through mode. A reset is successfully completed and the state machine set in an idle state in the cycle after $\overline{RESET}$ has been asserted for a minimum of 10 clock cycles and deasserted for five clock cycles.

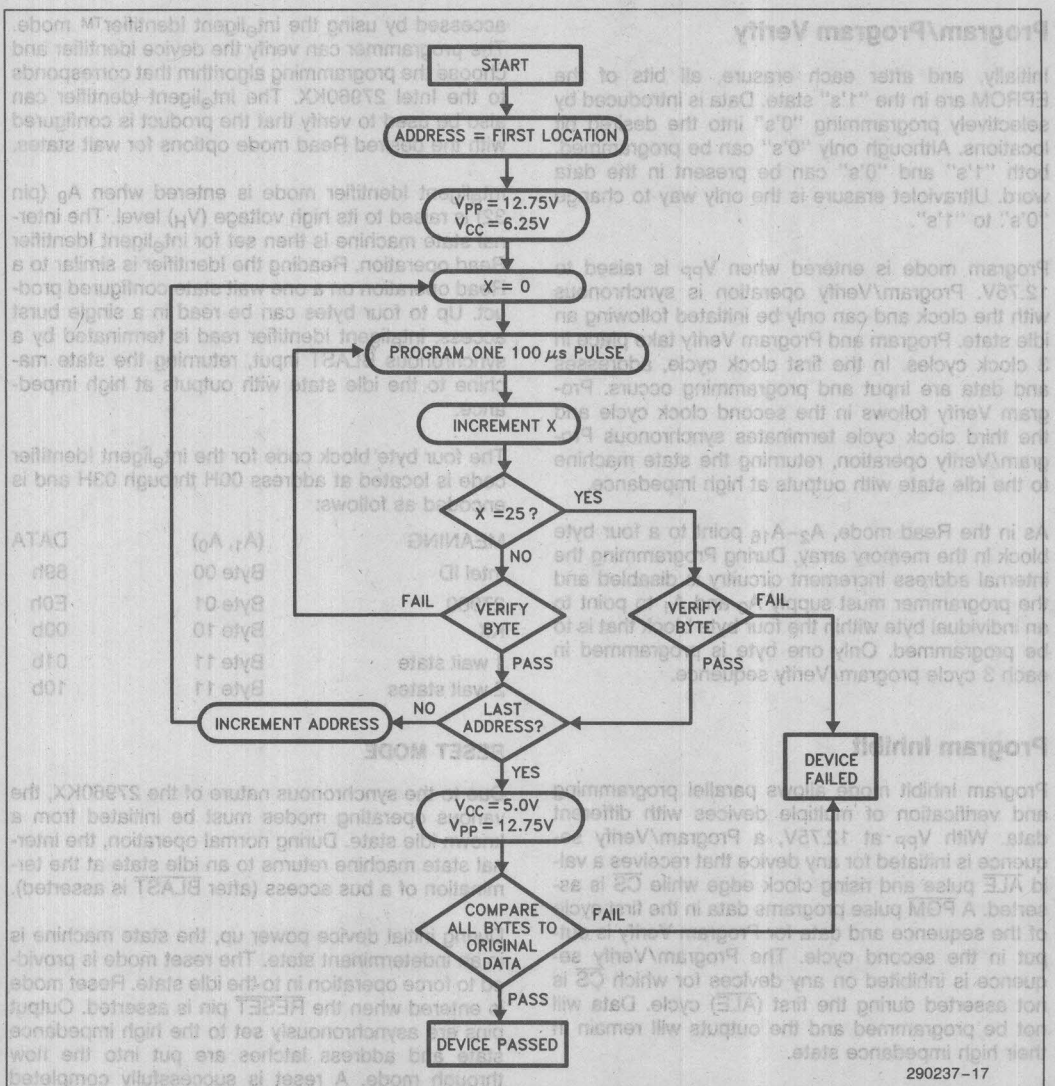


Figure 8. Quick-Pulse Programming™ Algorithm

ERASURE CHARACTERISTICS (FOR WINDOWED DEVICES)

Exposure to light of wavelength shorter than 4000 Angstroms begins erasure. Sunlight and some fluorescent lamps have wavelengths in the 3000–4000 Angstrom range. Constant exposure to room-level fluorescent light can erase the EPROM array in about 3 years (about 1 week for direct sunlight). Opaque labels over the window will prevent unintentional erasure under these lighting conditions.

The recommended erasure procedure is exposure to 2537 Angstrom ultraviolet light. The minimum integrated erasure time using a 12000 fW/cm2 ultraviolet lamp is approximately 15 to 20 minutes. The EPROM should be placed about 1 inch from the lamp. The maximum integrated dose is 7258 Wsec/cm2 (1 week @ 12000 fW/cm2). High intensity UV light exposure for longer periods can cause permanent damage.

QUICK-PULSE PROGRAMMING ALGORITHM

The Quick-Pulse Programming algorithm programs Intel's 27960KX. Developed to substantially reduce programming throughput time, this algorithm allows optimized equipment to program a 27960KX in under 17 seconds. Actual programming time depends on the programmer used.

The Quick-Pulse Programming algorithm uses a 100 μs pulse followed by a byte verfication to determine when the addressed byte is correctly programmed. The algorithm terminates if 25 100μs pulses fail to program a byte. Figure 8 shows the 27960KX Quick-Pulse Programming algorithm flowchart.

The entire program-pulse, byte-verify sequence is performed with V_{CC} = 6.25V and V_{PP} = 12.75V. The programming equipment must establish V_{CC} before applying voltages to any other pins. When programming is complete, all bytes should be compared to the original data with V_{CC} = 5.0V and V_{PP} = 12.75V.

D.C. PROGRAMMING CHARACTERISTICS T_A = 25°C ±5°C

Symbol	Parameter	Notes	Min	Max	Unit	Test Condition
I_{LI}	Input Load Current			10	μA	$V_{IN} = V_{IH}$ or V_{IL}
I_{CC}	V_{CC} Program Current	1		125	mA	$\overline{CS} = V_{IL}$
I_{PP}	V_{PP} Program Current	1		50	mA	$\overline{CS} = V_{IL}$
V_{IL}	Input Low Voltage		−0.5	0.8	V	
V_{IH}	Input High Voltage		2.0	V_{CC}+0.5	V	
V_{OL}	Output Low Voltage (Verify)			0.40	V	I_{OL} = 2.1 mA
V_{OH}	Output High Voltage (Verify)		V_{CC}−0.8		V	I_{OH} = −400 μA
V_{ID}	A_9 inteligent Identifier Voltage		11.5	12.5	V	
V_{CC}	Supply Voltage (Program)	2	6.0	6.5	V	
V_{PP}	Program Voltage	2	12.5	13.0	V	

NOTES:
1. The maximum current value is with outputs unloaded.
2. V_{CC} must be applied simultaneously or before V_{PP} and remove simultaneously or after V_{PP}.
3. During programming clock levels are V_{IH} and V_{IL}.

	t_{BVCH}	BLAST Valid to CLK High		50		ns
10	t_{CHBX}	CLK High to $\overline{BLAST}$ Invalid	4	50		ns
11	t_{QVPL}	DATA Valid to $\overline{PGM}$ Low		2		µs
12	t_{PLPH}	$\overline{PGM}$ Program Pulse Width		95	105	µs
13	t_{PHQX}	$\overline{PGM}$ High to D_{IN} Invalid		2		µs
14	t_{CLPL}	CLK Low to $\overline{PGM}$ Low		50		ns
15	t_{QZCH}	D_{IN} in Tri-State to CLK High		2		µs
16	t_{VCS}	V_{CC} Program Voltage to CLK High	7	2		µs
17	t_{VPS}	V_{PP} Program Voltage to CLK High	7	2		µs
18	t_{A_9HCH}	A_9 V_{ID} Voltage to CLK High		2		µs
19	t_{CHA_9X}	CLK High to A9 not V_{ID} Voltage		2		µs
20	t_{RVCH}	$\overline{RESET}$ Valid to CLK High	6	50		ns
21	t_{CHCL}	CLK High to CLK Low	5	100		ns
22	t_{CLCH}	CLK Low to CLK High	5	100		ns

NOTES:
1. If $\overline{CS}$ is low, $\overline{ALE}$ can go low no sooner than the falling edge of the previous CLK.
2. $\overline{ALE}$ must return high prior to the next rising edge of clock.
3. $\overline{CS}$ must remain low until after the rising edge CLK1.
4. $\overline{BLAST}$ must return high prior to the next rising edge of CLK.
5. Max CLK rise/fall time is 100 ns.
6. $\overline{RESET}$ must be held low for 10 cycles and high for 5 cycles before performing a read.
7. V_{CC} must be applied simultaneously or before V_{PP} and removed simultaneously or after V_{PP}.

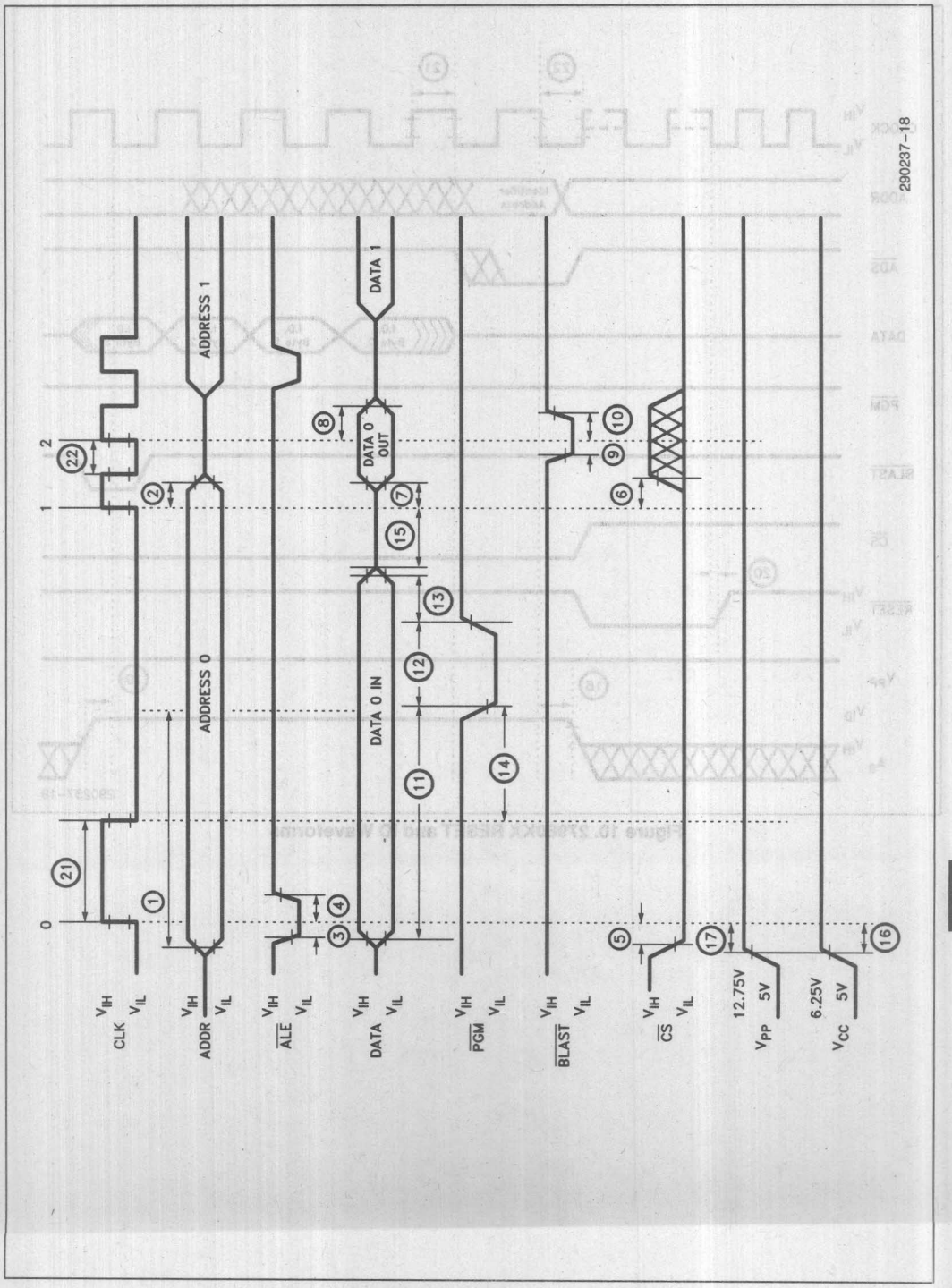


Figure 9. 27960KX Programming Waveforms

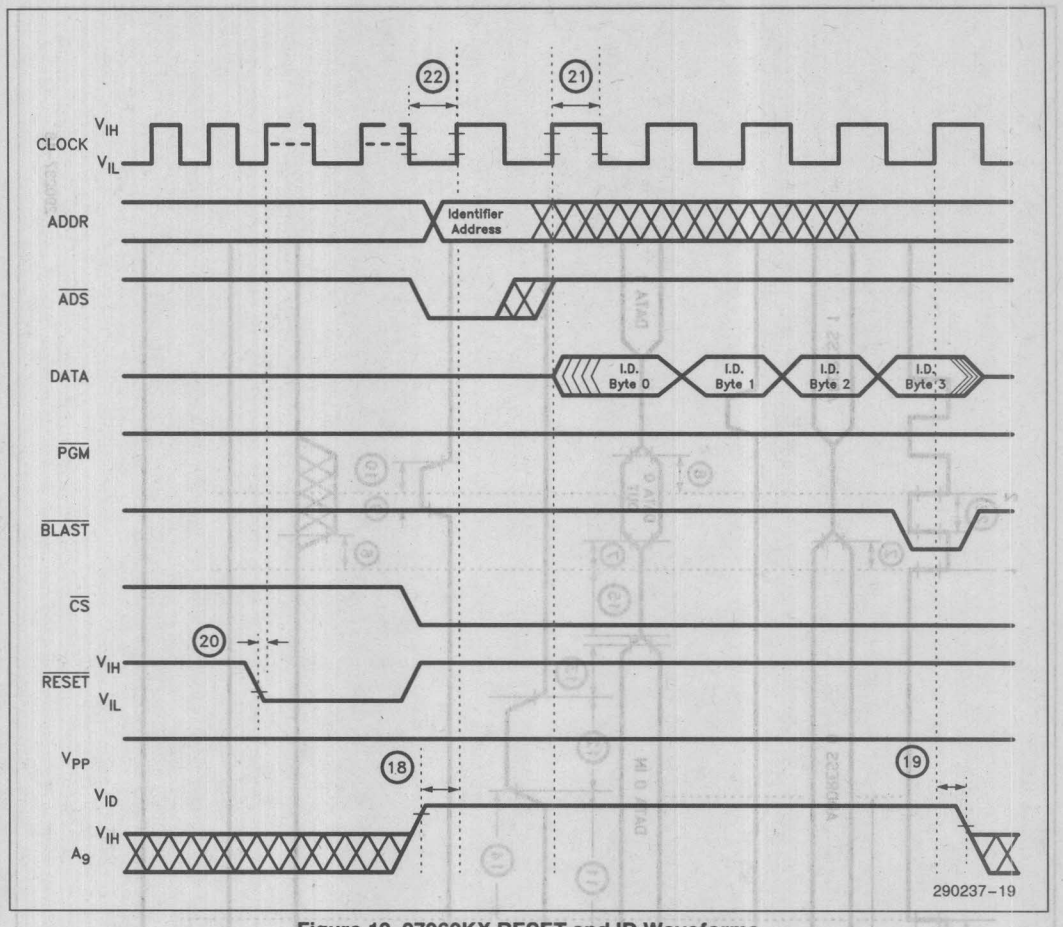


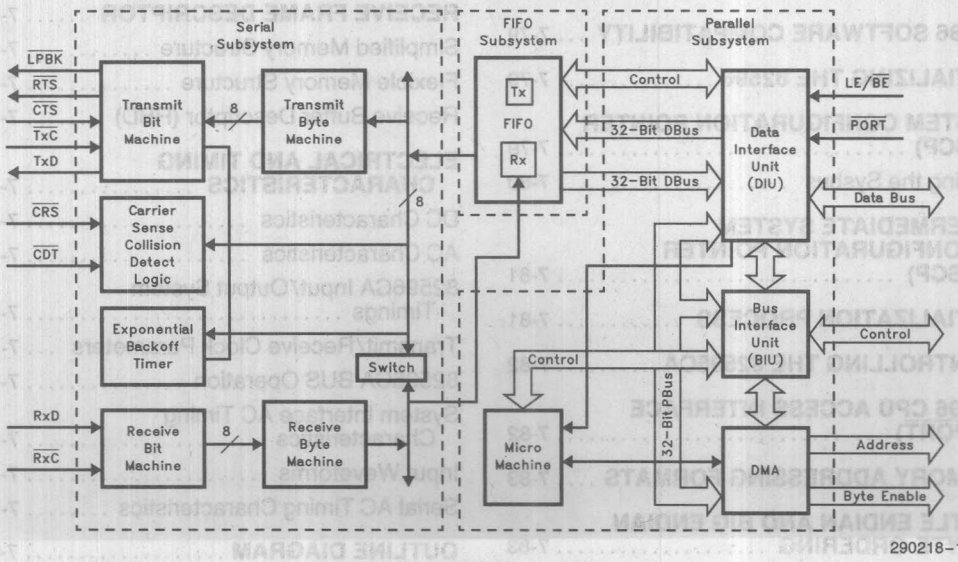
Figure 10. 27960KX RESET and ID Waveforms

82596CA
HIGH-PERFORMANCE 32-BIT LOCAL AREA NETWORK COPROCESSOR

- **Performs Complete CSMA/CD Medium Access Control (MAC) Functions—Independently of CPU**
  - **IEEE 802.3 (EOC) Frame Delimiting**
  - **HDLC Frame Delimiting**
- **Supports Industry Standard LANs**
  - **IEEE TYPE 10BASE5 (Ethernet*), IEEE TYPE 10BASE2 (Cheapernet), IEEE TYPE 1BASE5 (StarLAN), and the Proposed Standards TYPE 10BASE-T and 10BASE-F**
  - **Proprietary CSMA/CD Networks Up to 20 Mb/s**
- **On-Chip Memory Management**
  - **Automatic Buffer Chaining**
  - **Buffer Reclamation after Receipt of Bad Frames; Optional Save Bad Frames**
  - **32-Bit Segmented or Linear (Flat) Memory Addressing Formats**
- **Network Management and Diagnostics**
  - **Monitor Mode**
  - **32-Bit Statistical Counters**
- **82586 Software Compatible**
- **Optimized CPU Interface**
  - **Optimized Bus Interface to Intel's i486™ and 80960CA Processors**
  - **Supports Big Endian and Little Endian Byte Ordering**
- **32-Bit Bus Master Interface**
  - **106 MB/s Bus Bandwidth**
  - **Burst Bus Transfers**
  - **Bus Throttle Timers**
  - **Transfers Data at 100% of Serial Bandwidth**
  - **128-Byte Receive FIFO, 64-Byte Transmit FIFO**
- **Self-Test Diagnostics**
- **Configurable Initialization Root for Data Structures**
- **High-Speed, 5V, CHMOS** IV Technology**
- **132-Pin Plastic Quad Flat Pack (PQFP) and PGA Package**

(See Packaging Spec Order No. 231369)

i486 is a trademark of Intel Corporation.
*Ethernet is a registered trademark of Xerox Corporation.
**CHMOS is a patented process of Intel Corporation.



290218-1

Figure 1. 82596CA Block Diagram

October 1990
Order Number: 290218-003

82596CA High-Performance 32-Bit Local Area Network Coprocessor

CONTENTS

PAGE

INTRODUCTION 7-61

PIN DESCRIPTIONS 7-65

82596 AND HOST CPU INTERACTION 7-69

82596 BUS INTERFACE 7-69

82596 MEMORY ADDRESSING 7-69

82596 SYSTEM MEMORY STRUCTURE 7-71

TRANSMIT AND RECEIVE MEMORY STRUCTURES 7-72

TRANSMITTING FRAMES 7-75

RECEIVING FRAMES 7-76

82596 NETWORK MANAGEMENT AND DIAGNOSTICS 7-76

NETWORK PLANNING AND MAINTENANCE 7-78

STATION DIAGNOSTICS AND SELF-TEST 7-79

82586 SOFTWARE COMPATIBILITY ... 7-79

INITIALIZING THE 82596 7-79

SYSTEM CONFIGURATION POINTER (SCP) 7-79

Writing the Sysbus 7-80

INTERMEDIATE SYSTEM CONFIGURATION POINTER (ISCP) 7-81

INITIALIZATION PROCESS 7-81

CONTROLLING THE 82596CA 7-82

82596 CPU ACCESS INTERFACE (PORT) 7-82

MEMORY ADDRESSING FORMATS 7-83

LITTLE ENDIAN AND BIG ENDIAN *BYTE ORDERING* 7-83

COMMAND UNIT (CU) 7-83

CONTENTS

PAGE

RECEIVE UNIT (RU) 7-84

SYSTEM CONTROL BLOCK (SCB) 7-84

SCB OFFSET ADDRESSES 7-87

CBL Offset (Address) 7-87

RFA Offset (Address) 7-87

SCB STATISTICAL COUNTERS 7-88

Statistical Counter Operation 7-88

ACTION COMMANDS AND OPERATING MODES 7-89

NOP 7-90

Individual Address Setup 7-90

Configure 7-91

Multicast-Setup 7-97

Transmit 7-98

Jamming Rules 7-100

TDR 7-101

Dump 7-103

Diagnose 7-106

RECEIVE FRAME DESCRIPTOR 7-107

Simplified Memory Structure 7-107

Flexible Memory Structure 7-108

Receive Buffer Descriptor (RBD) 7-109

ELECTRICAL AND TIMING CHARACTERISTICS 7-114

DC Characteristics 7-114

AC Characteristics 7-115

82596CA Input/Output System Timings 7-115

Transmit/Receive Clock Parameters ... 7-117

82596CA BUS Operation 7-120

System Interface AC Timing Characteristics 7-121

Input Waveforms 7-122

Serial AC Timing Characteristics 7-124

OUTLINE DIAGRAM 7-126

REVISION HISTORY 7-130

INTRODUCTION

The 82596CA is an intelligent, high-performance 32-bit Local Area Network coprocessor. The 82596CA implements the CSMA/CD access method and can be configured to support all existing IEEE 802.3 standards—TYPEs 10BASE5, 10BASE2, 1BASE5, and 10BROAD36. It can also be used to implement the proposed standards TYPE 10BASE-T and 10BASE-F. The 82596CA performs high-level commands, command chaining, and interprocessor communications via shared memory, thus relieving the host CPU of many tasks associated with network control. All time-critical functions are performed independently of the CPU, this increases network performance and efficiency. The 82596CA bus interfaces is optimized for Intel's i486™, 80960CA, and 80960KB processors.

The 82596CA implements all IEEE 802.3 Medium Access Control and channel interface functions, these include framing, preamble generation and stripping, source address generation, destination address checking, short-frame detection, and automatic length-field handling. Data rates up to 20 Mb/s are supported.

The 82596CA provides a powerful host system interface. It manages memory structures automatically, with command chaining and bidirectional data chaining. An on-chip DMA controller manages four channels, this allows autonomous transfer of data blocks (buffers and frames) and relieves the CPU of byte transfer overhead. Buffers containing errored or collided frames can be automatically recovered without CPU intervention. The 82596CA provides an upgrade path for existing 82586 software drivers by providing an 82586-software-compatible mode that supports the current 82586 memory structure. The 82586CA also has a Flexible memory structure and a Simplified memory structure. The 82596CA can address up to 4 gigabytes of memory. The 82596CA supports Little Endian and Big Endian byte ordering.

The 82596CA bus interface can achieve a burst transfer rate of 106 MB/s at 33 MHz. The bus interface employs bus throttle timers to regulate 82596CA bus use. Two large, independent FIFOs—128 bytes for Receive and 64 bytes for Transmit—tolerate long bus latencies and provide programmable thresholds that allow the user to optimize bus overhead for any worst-case bus latency. The high-performance bus is capable of back-to-back transmission and reception during the IEEE 802.3 9.6-μs Interframe Spacing (IFS) period.

The 82596CA provides a wide range of diagnostics and network management functions, these include internal and external loopback, exception condition tallies, channel activity indicators, optional capture of all frames regardless of destination address (promiscuous mode), optional capture of errored or collided frames, and time domain reflectometry for locating fault points on the network cable. The statistical counters, in 32-bit segmented and linear modes, are 32-bits each and include CRC errors, alignment errors, overrun errors, resource errors, short frames, and received collisions. The 82596CA also features a monitor mode for network analysis. In this mode the 82596CA can capture status bytes, and update statistical counters, of frames monitored on the link without transferring the contents of the frames to memory. This can be done concurrently while transmitting and receiving frames destined for that station.

The 82596CA can be used in both baseband and broadband networks. It can be configured for maximum network efficiency (minimum contention overhead) with networks of any length. Its highly flexible CSMA/CD unit supports address field lengths of zero through six bytes—configurable to either IEEE 802.3/Ethernet or HDLC frame delimitation. It also supports 16- or 32-bit cyclic redundancy checks. The CRC can be transferred directly to memory for receive operations, or dynamically inserted for transmit operations. The CSMA/CD unit can also be configured for full duplex operation for high throughput in point-to-point connections.

The 82596CA is fabricated with Intel's reliable, 5-V, CHMOS IV technology. It is available in a 132-pin PQFP or PGA package.

Figure 2. 82596CA PQFP Pin Configuration

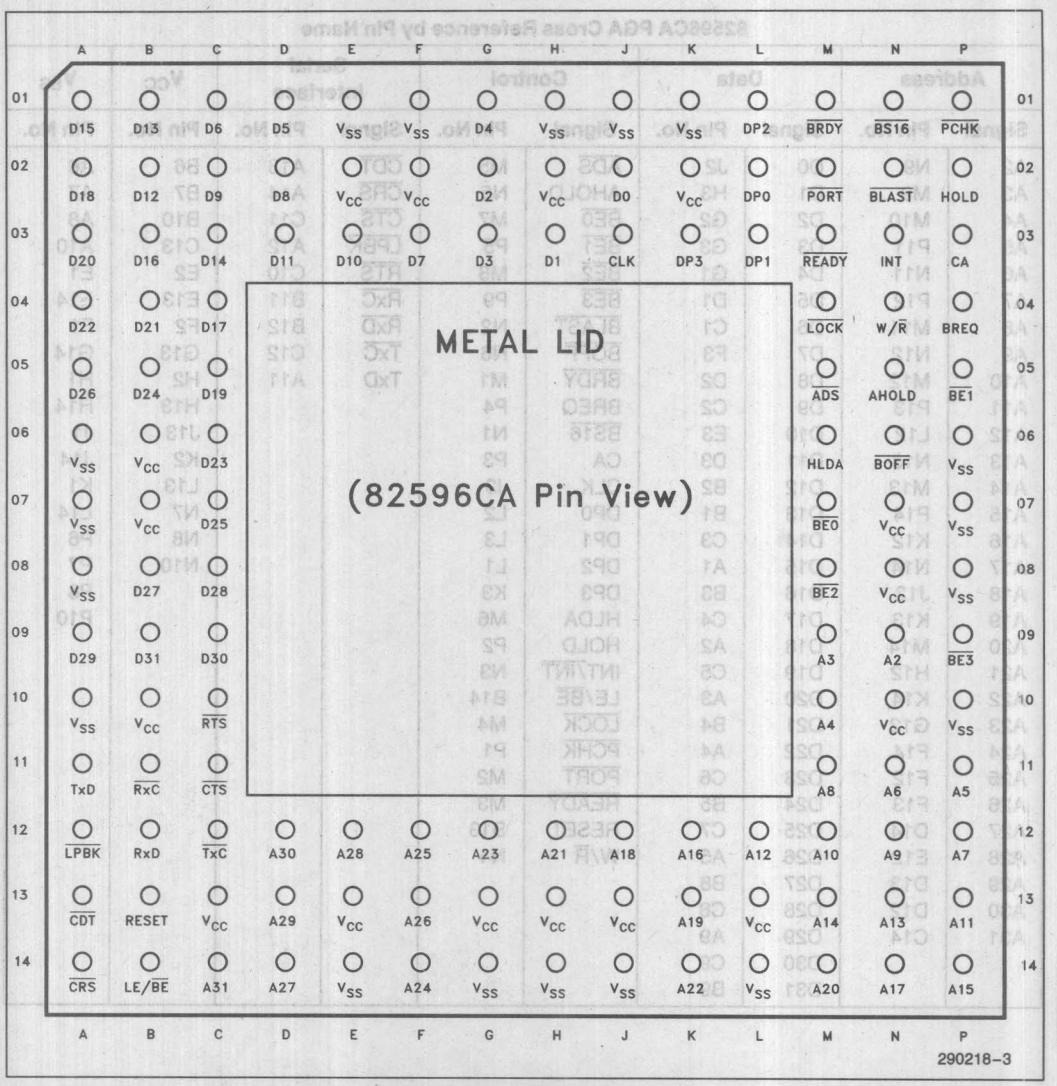


Figure 3. 82596CA PGA Pinout

82596CA PGA Cross Reference by Pin Name

Address		Data		Control		Serial Interface		V_{CC}	V_{SS}
Signal	Pin No.	Signal	Pin No.	Signal	Pin No.	Signal	Pin No.	Pin No.	Pin No.
A2	N9	D0	J2	$\overline{ADS}$	M5	$\overline{CDT}$	A13	B6	A6
A3	M9	D1	H3	AHOLD	N5	$\overline{CRS}$	A14	B7	A7
A4	M10	D2	G2	$\overline{BE0}$	M7	$\overline{CTS}$	C11	B10	A8
A5	P11	D3	G3	$\overline{BE1}$	P5	$\overline{LPBK}$	A12	C13	A10
A6	N11	D4	G1	$\overline{BE2}$	M8	$\overline{RTS}$	C10	E2	E1
A7	P12	D5	D1	$\overline{BE3}$	P9	$\overline{RxC}$	B11	E13	E14
A8	M11	D6	C1	$\overline{BLAST}$	N2	$\overline{RxD}$	B12	F2	F1
A9	N12	D7	F3	$\overline{BOFF}$	N6	$\overline{TxC}$	C12	G13	G14
A10	M12	D8	D2	$\overline{BRDY}$	M1	TxD	A11	H2	H1
A11	P13	D9	C2	BREQ	P4			H13	H14
A12	L12	D10	E3	$\overline{BS16}$	N1			J13	J1
A13	N13	D11	D3	CA	P3			K2	J14
A14	M13	D12	B2	CLK	J3			L13	K1
A15	P14	D13	B1	DP0	L2			N7	L14
A16	K12	D14	C3	DP1	L3			N8	P6
A17	N14	D15	A1	DP2	L1			N10	P7
A18	J12	D16	B3	DP3	K3				P8
A19	K13	D17	C4	HLDA	M6				P10
A20	M14	D18	A2	HOLD	P2				
A21	H12	D19	C5	INT/$\overline{INT}$	N3				
A22	K14	D20	A3	LE/$\overline{BE}$	B14				
A23	G12	D21	B4	$\overline{LOCK}$	M4				
A24	F14	D22	A4	$\overline{PCHK}$	P1				
A25	F12	D23	C6	$\overline{PORT}$	M2				
A26	F13	D24	B5	$\overline{READY}$	M3				
A27	D14	D25	C7	RESET	B13				
A28	E12	D26	A5	W/$\overline{R}$	N4				
A29	D13	D27	B8						
A30	D12	D28	C8						
A31	C14	D29	A9						
		D30	C9						
		D31	B9						

PIN DESCRIPTIONS

Symbol	PQFP Pin No.	Type	Name and Function
CLK	9	I	**CLOCK.** The system clock input provides the fundamental timing for the 82596. It is a 1X CLK input used to generate the 82596 clock and requires TTL levels. All external timing parameters are specified in reference to the rising edge of CLK.
D0–D31	14–53	I/O	**DATA BUS.** The 32 Data Bus lines are bidirectional, tri-state lines that provide the general purpose data path between the 82596 and memory. With the 82596 the bus can be either 16 or 32 bits wide; this is determined by the $\overline{BS16}$ signal. The 82596 always drives all 32 data lines during Write operations, even with a 16-bit bus. D31– D0 are floated after a Reset or when the bus is not acquired. These lines are inputs during a CPU Port access; in this mode the CPU writes the next address to the 82596 through the data lines. During $\overline{PORT}$ commands (Relocatable SCP, Self-Test, Reset and Dump) the address must be aligned to a 16-byte boundary. This frees the D_3–D_0 lines so they can be used to distinguish the commands. The following is a summary of the decoding data.

D0	D1	D2	D3	D31–D4	Function
0	0	0	0	0000	Reset
0	1	0	0	ADDR	Relocatable SCP
1	0	0	0	ADDR	Self-Test
1	1	0	0	ADDR	Dump Command

DP0–DP3	4–7	I/O	**DATA PARITY.** These are tri-stated data parity pins. There is one parity line for each byte of the data bus. The 82596 drives them with even-parity information during write operations having the same timing as data writes. Likewise, even-parity information, with the same timing as read information, must be driven back to the 82596 over these pins to ensure that the correct parity check status is indicated by the 82596.
$\overline{PCHK}$	127	O	**PARITY CHECK.** This pin is driven high one clock after $\overline{RDY}$ to inform Read operations of the parity status of data sampled at the end of the previous clock cycle. When driven low it indicates that incorrect parity data has been sampled. It only checks the parity status of enabled bytes, which are indicated by the Byte Enable and Bus Size signals. $\overline{PCHK}$ is only valid for one clock time after data read is returned to the 82596; i.e., it is inactive (high) at all other times.
A31-A2	7008	O	**ADDRESS LINES.** These 30 tri-stated Address lines output the address bits required for memory operation. These lines are floated after a Reset or when the bus is not acquired.
$\overline{BE3}$–$\overline{BE0}$	109–114	O	**BYTE ENABLE.** These tri-stated signals are used to indicate which bytes are involved with the current memory access. The number of Byte Enable signals asserted indicates the physical size of the data being transferred (1, 2, 3, or 4 bytes). • $\overline{BE0}$ indicates D7–D0 • $\overline{BE1}$ indicates D15–D8 • $\overline{BE2}$ indicates D23–D16 • $\overline{BE3}$ indicates D31–D24 These lines are floated after a Reset or when the bus is not acquired.
W/$\overline{R}$	120	O	**WRITE/READ.** This dual function pin is used to distinguish Write and Read cycles. This line is floated after a Reset or when the bus is not acquired.

7

PIN DESCRIPTIONS (Continued)

Symbol	PQFP Pin No.	Type	Name and Function
$\overline{ADS}$	124	O	**ADDRESS STATUS.** The 82596 uses this tri-state pin to indicate to indicate that a valid bus cycle has begun and that A31–A2, $\overline{BE3}$–$\overline{BE0}$, and W/$\overline{R}$ are being driven. It is asserted during t1 bus states. This line is floated after a Reset or when the bus is not acquired.
$\overline{RDY}$	130	I	**READY.** Active low. This signal is the acknowledgment from addressed memory that the transfer cycle can be completed. When high, it causes wait states to be inserted. It is ignored at the end of the first clock of the bus cycle's data cycle. This active-low signal does not have an internal pull-up resistor. This signal must meet the setup and hold times to operate correctly.
$\overline{BRDY}$	2	I	**BURST READY.** Active low. Burst Ready, like $\overline{RDY}$, indicates that the external system has presented valid data on the data pins in response to a Read, or that the external system has accepted the 82596 data in response to a Write request. Also, like $\overline{RDY}$, this signal is ignored at the end of the first clock in a bus cycle. If the 82596 can still receive data from the previous cycle, ADS will not be asserted in the next clock cycle; however, Address and Byte Enable will change to reflect the next data item expected by the 82596. $\overline{BRDY}$ will be sampled during each succeeding clock and if active, the data on the pins will be strobed to the 82596 or to external memory (read/write). $\overline{BRDY}$ operates exactly like READY during the last data cycle of a burst sequence and during nonburstable cycles.
$\overline{BLAST}$	128	O	**BURST LAST.** A signal (active low) on this tri-state pin indicates that the burst cycle is finished and when $\overline{BRDY}$ is next returned it will be treated as a normal ready; i.e., another set of addresses will be driven with $\overline{ADS}$ or the bus will go idle. $\overline{BLAST}$ is not asserted if the bus is not acquired.
AHOLD	117	I	**ADDRESS HOLD.** This hold signal is active high, it allows another bus master to access the 82596 address bus. In a system where an 82596 and an i486 processor share the local bus, AHOLD allows the cache controller to make a cache invalidation cycle while the 82596 holds the address lines. In response to a signal on this pin, the 82596 immediately (i.e. during the next clock) stops driving the entire address bus (A31–A2); the rest of the bus can remain active. For example, data can be returned for a previously specified bus cycle during Address Hold. The 82596 will not begin another bus cycle while AHOLD is active.
$\overline{BOFF}$	116	I	**BACKOFF.** This signal is active low, it informs the 82596 that another bus master requires access to the bus before the 82596 bus cycle completes. The 82596 immediately (i.e. during the next clock) floats its bus. Any data returned to the 82596 while $\overline{BOFF}$ is asserted is ignored. $\overline{BOFF}$ has higher priority than $\overline{RDY}$ or $\overline{BRDY}$; if two such signals are returned in the same clock period, $\overline{BOFF}$ is given preference. The 82596 remains in Hold until $\overline{BOFF}$ goes high, then the 82596 resumes its bus cycle by driving out the address and status, and asserting $\overline{ADS}$.
$\overline{LOCK}$	126	O	**LOCK.** This tri-state pin is used to distinguish locked and unlocked bus cycles. $\overline{LOCK}$ generates a semaphore handshake to the CPU. $\overline{LOCK}$ can be active for several memory cycles, it goes active during the first locked memory cycle (t1) and goes inactive at the last locked cycle (t2). This line is floated after a Reset or when the bus is not acquired. $\overline{LOCK}$ can be disabled via the sysbus byte in software.

PIN DESCRIPTIONS (Continued)

Symbol	PQFP Pin No.	Type	Name and Function
$\overline{BS16}$	129	I	**BUS SIZE.** This signal allows the 82596CA to work with either 16- or 32-bit bytes. Inserting $\overline{BS16}$ low causes the 82596 to perform two 16-bit memory accesses when transferring 32-bit data. In little endian mode the D15–D0 lines are driven when $\overline{BS16}$ is inserted, in Big Endian mode the D31–D16 lines are driven.
HOLD	123	O	**HOLD.** The HOLD signal is active high, the 82596 uses it to request local bus mastership. In normal operation HOLD goes inactive before HLDA. The 82596 can be forced off the bus by deasserting HLDA or if the bus throttle timers expire.
HLDA	118	I	**HOLD ACKNOWLEDGE.** The HLDA signal is active high, it indicates that bus mastership has been given to the 82596. HLDA is internally synchronized; after HOLD is detected low, the CPU drives HLDA low. **NOTE** *Do not connect HLDA to V_{CC}—it will cause a deadlock.* A user wanting to give the 82596 permanent access to the bus should connect HLDA to HOLD. If HLDA goes inactive before HOLD, the 82596 will release the bus (by deasserting HOLD) within a maximum of within a specified number of bus cycles as specified in the 82596 User's Manual.
BREQ	115	I	**BUS REQUEST.** This signal, when configured to an externally activated mode, is used to trigger the bus throttle timers.
$\overline{PORT}$	3	I	**PORT.** When this signal is received, the 82596 latches the data on the data bus into an internal 32-bit register. When the CPU is asserting this signal it can write into the 82596 (via the data bus). This pin must be activated twice during all CPU Port access commands.
RESET	69	I	**RESET.** This active high, internally synchronized signal causes the 82596 to terminate current activity. The signal must be high for at least five system clock cycles. After five system clock cycles and four $\overline{TxC}$ clock cycles the 82596 will execute a Reset when it receives a high RESET signal. When RESET returns to low the 82596 waits for the first CA signal and then begins the initialization sequence.
LE/$\overline{BE}$	65	I	**LITTLE ENDIAN/BIG ENDIAN.** This dual-function pin is used to select byte ordering. When LE/$\overline{BE}$ is high, little endian byte ordering is used; when low, big endian byte ordering is used for data in frames (bytes) and for control (SCB, RFD, CBL, etc).
CA	119	I	**CHANNEL ATTENTION.** The CPU uses this pin to force the 82596 to begin executing memory resident Command blocks. The CA signal is internally synchronized. The signal must be high for at least one system clock. It is latched internally on the high to low edge and then detected by the 82596. The first CA after a Reset forces the 82596 into the initialization sequence beginning at location 00FFFFF6h or an SCP address written to the 82596 using CPU Port access. All subsequent CA signals cause the 82596 to begin executing new command sequences from the SCB.
INT/$\overline{INT}$	125	O	**INTERRUPT.** A high signal on this pin notifies the CPU that the 82596 is requesting an interrupt. This signal is an edge triggered interrupt signal, and can be configured to be active high or low.

PIN DESCRIPTIONS (Continued)

Symbol	PQFP Pin No.	Type	Name and Function
V_{CC}	18 Pins		**POWER.** +5 V ±10%.
V_{SS}	18 Pins		**GROUND.** 0 V.
TxD	54	O	**TRANSMIT DATA.** This pin transmits data to the serial link. It is high when not transmitting.
$\overline{TxC}$	64	I	**TRANSMIT CLOCK.** This signal provides the fundamental timing for the serial subsystem. The clock is also used to transmit data synchronously on the TxD pin. For NRZ encoding, data is transferred to the TxD pin on the high to low clock transition. For Manchester encoding, the transmitted bit center is aligned with the low to high transition. Transmit clock must always be running for proper device operation.
$\overline{LPBK}$	58	O	**LOOPBACK.** This TTL-level control signal enables the loopback mode. In this mode serial data on the TxD input is routed through the 82C501 internal circuits and back to the RxD output without driving the transceiver cable. To enable this signal, both internal and external loopback need to be set with the Configure command.
RxD	60	I	**RECEIVE DATA.** This pin receives NRZ serial data only. It must be high when not receiving.
$\overline{RxC}$	59	I	**RECEIVE CLOCK.** This signal provides timing information to the internal shifting logic. For NRZ data the state of the RxD pin is sampled on the high to low transition of the clock.
$\overline{RTS}$	57	O	**REQUEST TO SEND.** When this signal is low the 82596 informs the external interface that it has data to transmit. It is forced high after a Reset or when transmission is stopped.
$\overline{CTS}$	62	I	**CLEAR TO SEND.** An active-low signal that enables the 82596 to send data. It is normally used as an interface handshake to $\overline{RTS}$. Asserting $\overline{CTS}$ high stops transmission. $\overline{CTS}$ is internally synchronized. If $\overline{CTS}$ goes inactive, meeting the setup time to the $\overline{TxC}$ negative edge, the transmission will stop and $\overline{RTS}$ will go inactive within, at most, two $\overline{TxC}$ cycles.
$\overline{CRS}$	63	I	**CARRIER SENSE.** This signal is active low, it is used to notify the 82596 that traffic is on the serial link. It is only used if the 82596 is configured for external Carrier Sense. In this configuration external circuitry is required for detecting traffic on the serial link. $\overline{CRS}$ is internally synchronized. To be accepted, the signal must remain active for at least two serial clock cycles (for CRSF = 0).
$\overline{CDT}$	61	I	**COLLISION DETECT.** This active-low signal informs the 82596 that a collision has occurred. It is only used if the 82596 is configured for external Collision Detect. External circuitry is required for collision detection. $\overline{CDT}$ is internally synchronized. To be accepted, the signal must remain active for at least two serial clock cycles (for CDTF = 0).

82596 AND HOST CPU INTERACTION

The 82596CA and the host CPU communicate through shared memory. Because of its on-chip DMA capability, the 82596 can make data block transfers (buffers and frames) independently of the CPU; this greatly reduces the CPU byte transfer overhead.

The 82596 is a multitasking coprocessor that comprises two independent logical units—the Command Unit (CU) and the Receive Unit (RU). The CU executes commands from shared memory. The RU handles all activities related to frame reception. The independence of the CU and RU enables the 82596 to engage in both activities simultaneously—the CU can fetch and execute commands from memory while the RU is storing received frames in memory. The CPU is only involved with this process after the CU has executed a sequence of commands or the RU has finished storing a sequence of frames.

The CPU and the 82596 use the hardware signals Interrupt (INT) and Channel Attention (CA) to initiate communication with the System Control Block (SCB), see Figure 4. The 82596 uses INT to alert the CPU of a change in the contents of the SCB, the CPU uses CA to alert the 82596.

The 82596 has a CPU Port Access state that allows the CPU to execute certain functions without accessing memory. The 82596 $\overline{\text{PORT}}$ pin and data bus pins are used to enable this feature. The CPU can directly activate four operations when the 82596 is in this state.

- Write an alternative System Configuration Pointer (SCP). This can be used when the 82596 cannot use the default SCP address space.
- Write a different Dump Command Pointer and execute Dump. This can be used for troubleshooting No Response problems.
- The CPU can reset the 82596 via software without disturbing the rest of the system.
- A self-test can be used for board testing; the 82596 will execute a self-test and write the results to memory.

82596 BUS INTERFACE

The 82596CA has bus interface timings and pin definitions that are compatible with Intel's 32-bit i486 microprocessor. This eliminates the need for additional bus interface logic. Operating at 33 MHz, the 82596's bus bandwidth can be as high as 106 MB/s. Since Ethernet only requires 1.25 MB/s, this leaves a considerable amount of bandwidth for the CPU. The 82596 also has a bus throttle to regulate its use of the bus. Two timers can be programmed through the SCB: one controls the maximum time the 82596 can remain on the bus, the other controls the time the 82596 must stay off the bus (see Figure 5). The bus throttle can be programmed to trigger internally with HLDA or externally with BREQ. These timers can restrict the 82596 HOLD activation time and improve bus utilization.

82596 MEMORY ADDRESSING

The 82596 has a 32-bit memory address range, which allows addressing up to four gigabytes of memory. The 82596 has three memory addressing modes (see Table 1).

- **82586 Mode.** The 82596 has a 24-bit memory address range. The System Control Block, Command List, Receive Descriptor List, and Buffer Descriptors must reside in one 64-KB memory segment. Transmit and Receive buffers can reside in a 24-bit address space.
- **32-Bit Segmented Mode.** The 82596 has a 32-bit memory address range. The System Control Block, Command List, Receive Descriptor List, and Buffer Descriptors must reside in one 64-KB memory segment. Transmit and Receive buffers can reside in a 32-bit address space.
- **Linear Mode.** The 82596 has a 32-bit memory address range. Any memory structure can reside anywhere within the 32-bit memory address range.

7

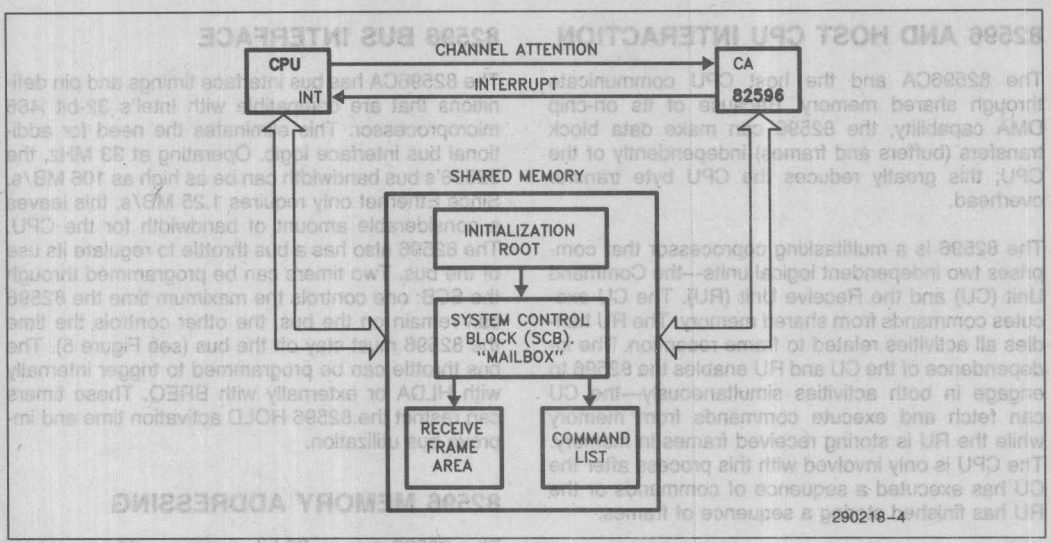


Figure 4. 82596 and Host CPU Intervention

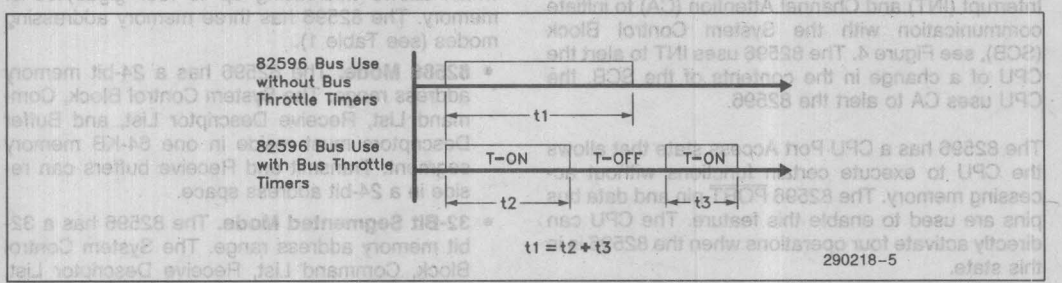


Figure 5. Bus Throttle Timers

Table 1. 82596 Memory Addressing Formats

Pointer or Offset	Operation Mode		
	82586	32-Bit Segmented	Linear
ISCP Address	24-Bit Linear	32-Bit Linear	32-Bit Linear
SCB Address	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Command Block Pointers	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Rx Frame Descriptors	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Tx Frame Descriptors	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Rx Buffer Descriptors	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Tx Buffer Descriptors	Base (24) + Offset (16)	Base (32) + Offset (16)	32-Bit Linear
Rx Buffers	24-Bit Linear	32-Bit Linear	32-Bit Linear
Tx Buffers	24-Bit Linear	32-Bit Linear	32-Bit Linear

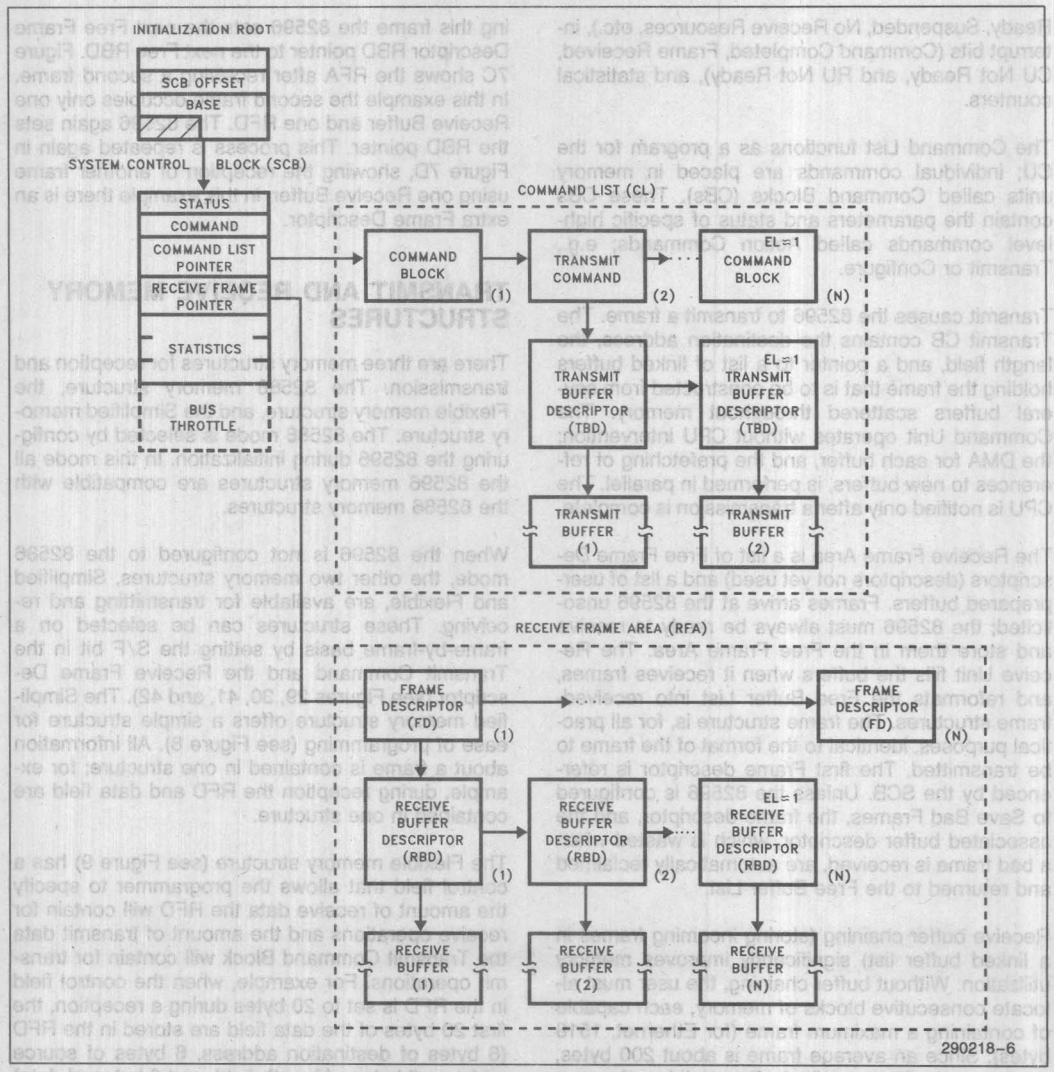


Figure 6. 82596 Shared Memory Structure

82596 SYSTEM MEMORY STRUCTURE

The Shared Memory structure consists of four parts: the Initialization Root, the System Control Block, the Command List, and the Receive Frame Area (see Figure 6).

The Initialization Root is in an established location known to the host CPU and the 82596 (00FFFFF6h). However, the CPU can establish the Initialization Root in another location by using the CPU Port access. This root is accessed during initialization, and points to the System Control Block.

The System Control Block serves as a bidirectional mail drop for the host CPU and the 82596 CU and RU. It is the central point through which the CPU and the 82596 exchange control and status information. The SCB has two areas. The first contains instructions from the CPU to the 82596. These include: control of the CU and RU (Start, Abort, Suspend, and Resume), a pointer to the list of CU commands, a pointer to the Receive Frame Area, a set of Interrupt Acknowledge bits, and the T-ON and T-OFF timers for the bus throttle. The second area contains status information the 82596 is sending to the CPU. Such as, the CU and RU states (Idle, Active

Ready, Suspended, No Receive Resources, etc.), interrupt bits (Command Completed, Frame Received, CU Not Ready, and RU Not Ready), and statistical counters.

The Command List functions as a program for the CU; individual commands are placed in memory units called Command Blocks (CBs). These CBs contain the parameters and status of specific high-level commands called Action Commands; e.g., Transmit or Configure.

Transmit causes the 82596 to transmit a frame. The Transmit CB contains the destination address, the length field, and a pointer to a list of linked buffers holding the frame that is to be constructed from several buffers scattered throughout memory. The Command Unit operates without CPU intervention; the DMA for each buffer, and the prefetching of references to new buffers, is performed in parallel. The CPU is notified only after a transmission is complete.

The Receive Frame Area is a list of Free Frame Descriptors (descriptors not yet used) and a list of user-prepared buffers. Frames arrive at the 82596 unsolicited; the 82596 must always be ready to receive and store them in the Free Frame Area. The Receive Unit fills the buffers when it receives frames, and reformats the Free Buffer List into received-frame structures. The frame structure is, for all practical purposes, identical to the format of the frame to be transmitted. The first Frame descriptor is referenced by the SCB. Unless the 82596 is configured to Save Bad Frames, the frame descriptor, and the associated buffer descriptor, which is wasted when a bad frame is received, are automatically reclaimed and returned to the Free Buffer List.

Receive buffer chaining (storing incoming frames in a linked buffer list) significantly improves memory utilization. Without buffer chaining, the user must allocate consecutive blocks of memory, each capable of containing a maximum frame (for Ethernet, 1518 bytes). Since an average frame is about 200 bytes, this is very inefficient. With buffer chaining, the user can allocate small buffers and the 82596 will only use those that are needed.

Figure 7 A–D illustrates how the 82596 uses the Receive Frame Area. Figure 7A shows an unused Receive Frame Area composed of Free Frame Descriptors and Free Receive Buffers prepared by the user. The SCB points to the first Frame Descriptor of the Frame Descriptor List. Figure 7B shows the same Receive Frame Area after receiving one frame. This first frame occupies two Receive Buffers and one Frame Descriptor—a valid received frame will only occupy one Frame Descriptor. After receiving this frame the 82596 sets the next Free Frame Descriptor RBD pointer to the next Free RBD. Figure 7C shows the RFA after receiving a second frame. In this example the second frame occupies only one Receive Buffer and one RFD. The 82596 again sets the RBD pointer. This process is repeated again in Figure 7D, showing the reception of another frame using one Receive Buffer; in this example there is an extra Frame Descriptor.

TRANSMIT AND RECEIVE MEMORY STRUCTURES

There are three memory structures for reception and transmission. The 82586 memory structure, the Flexible memory structure, and the Simplified memory structure. The 82586 mode is selected by configuring the 82596 during initialization. In this mode all the 82596 memory structures are compatible with the 82586 memory structures.

When the 82596 is not configured to the 82586 mode, the other two memory structures, Simplified and Flexible, are available for transmitting and receiving. These structures can be selected on a frame-by-frame basis by setting the S/F bit in the Transmit Command and the Receive Frame Descriptor (see Figures 29, 30, 41, and 42). The Simplified memory structure offers a simple structure for ease of programming (see Figure 8). All information about a frame is contained in one structure; for example, during reception the RFD and data field are contained in one structure.

The Flexible memory structure (see Figure 9) has a control field that allows the programmer to specify the amount of receive data the RFD will contain for receive operations and the amount of transmit data the Transmit Command Block will contain for transmit operations. For example, when the control field in the RFD is set to 20 bytes during a reception, the first 20 bytes of the data field are stored in the RFD (6 bytes of destination address, 6 bytes of source address, 2 bytes of length field, and 6 bytes of data) and the remainder of the data field is stored in the Receive Data Buffers. This is useful for capturing frame headers when header information is contained in the data field. The header information can then be automatically stored in the RFD partitioned from the Receive Data Buffer.

The control field can also be used for the Transmit Command when the Flexible memory structure is used. The quantity of data field bytes to be transmitted from the Transmit Command Block is specified by the variable control field.

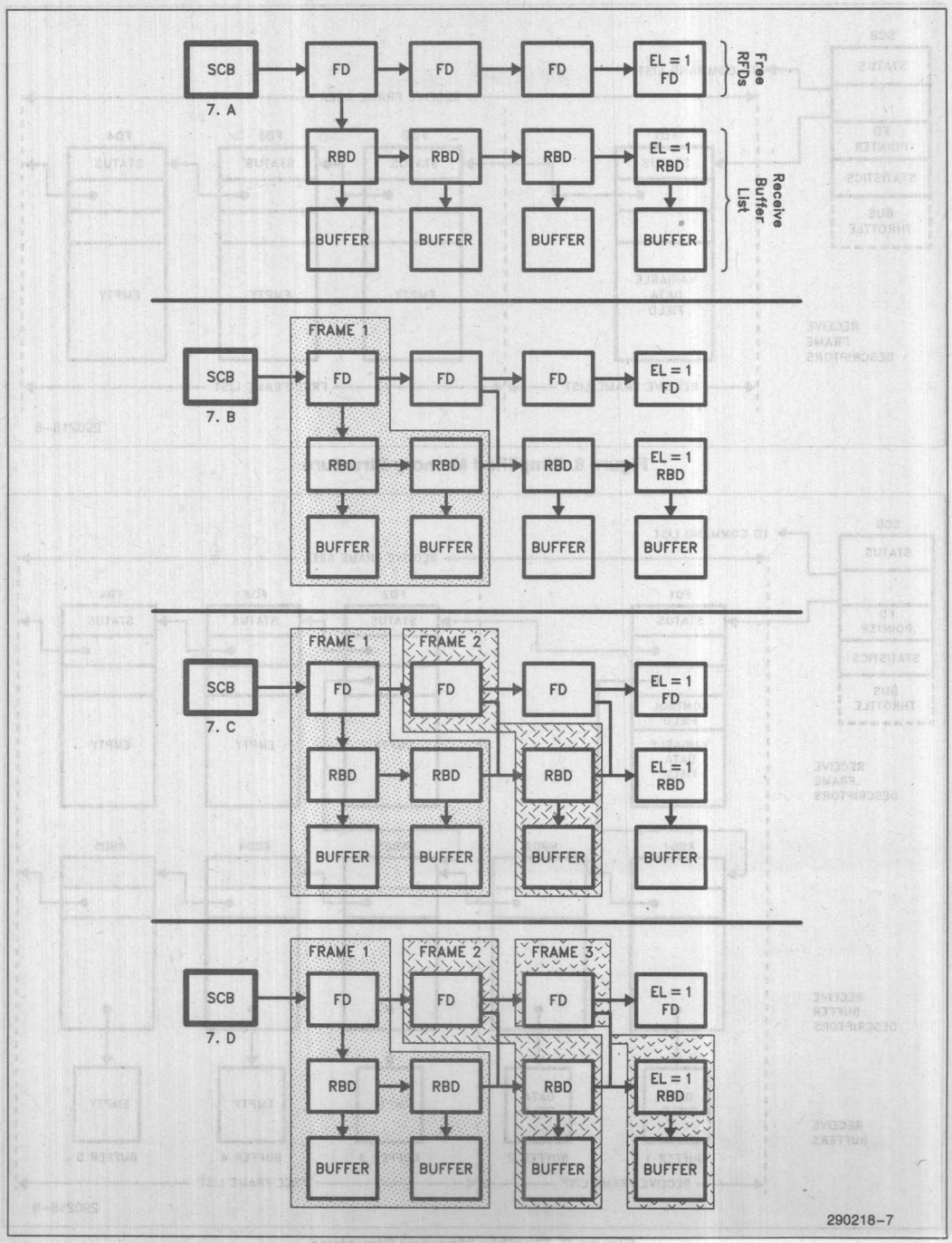


Figure 7. Frame Reception in the RFA

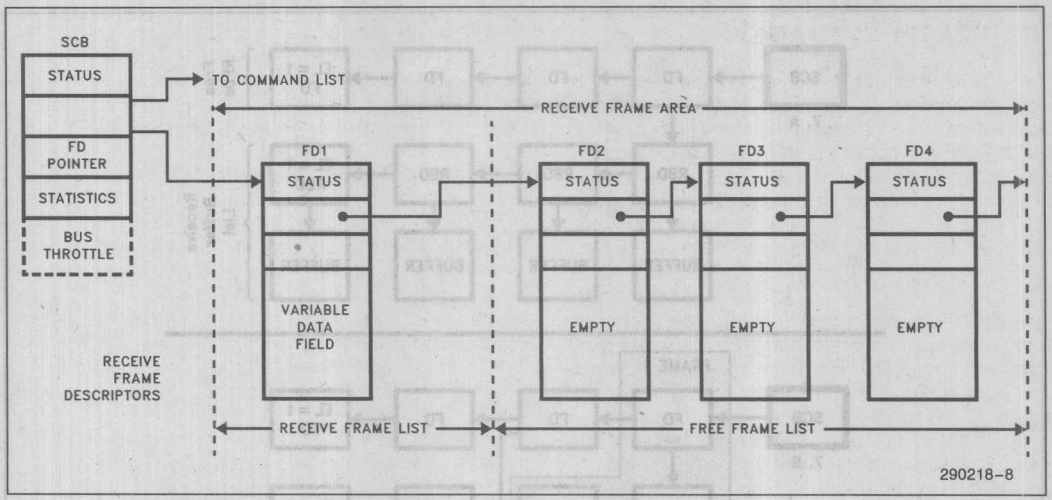


Figure 8. Simplified Memory Structure

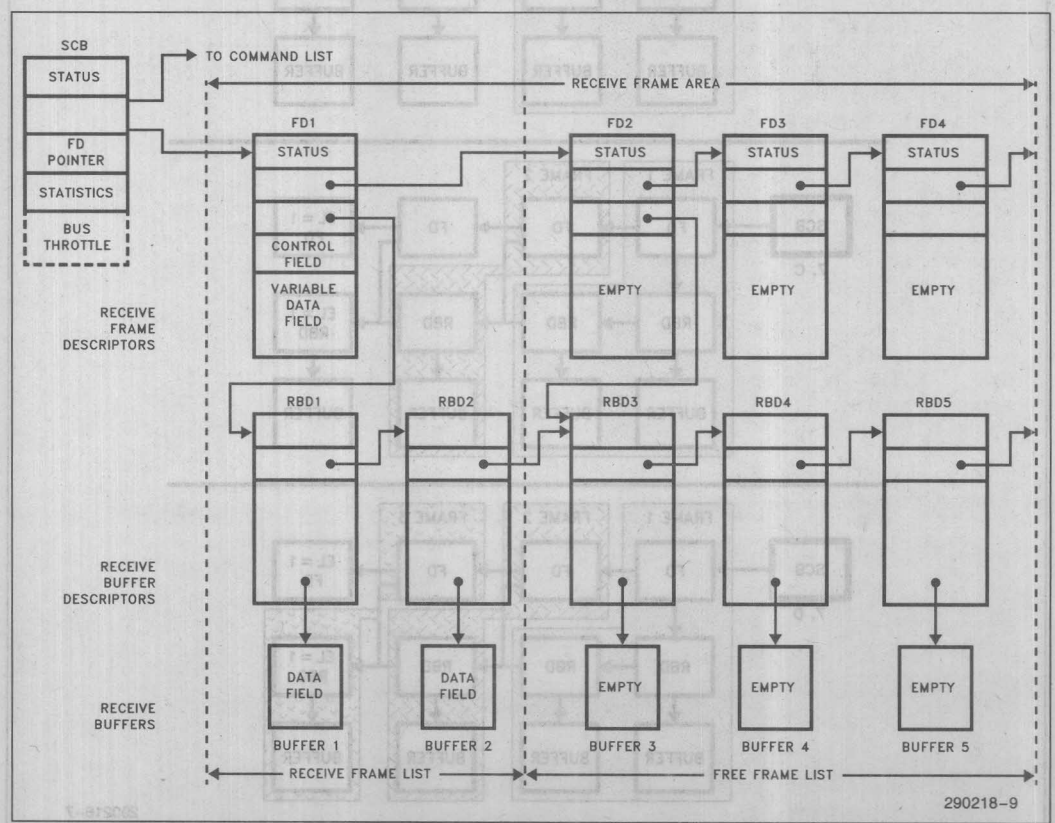


Figure 9. Flexible Memory Structure

TRANSMITTING FRAMES

The 82596 executes high-level Action Commands from the Command List in system memory. Action Commands are fetched and executed in parallel with the host CPU operation, thereby significantly improving system performance. The format of the Action Commands is shown in Figure 10. Figure 28 shows the 82586 mode, and Figures 29 and 30 show the command formats of the Linear and 32-bit Segmented modes.

A single Transmit command contains, as part of the command-specific parameters, the destination address and length field of the transmitted frame and a pointer to buffer area in memory containing the data portion of the frame. The data field is contained in a memory data structure consisting of a buffer descriptor (BD) and a data buffer—or a linked list of buffer descriptors and buffers—as shown in Figure 11.

Multiple data buffers can be chained together using the BDs. Thus, a frame with a long data field can be transmitted using several (shorter) data buffers chained together. This chaining technique allows the system designer to develop efficient buffer management.

The 82596 automatically generates the preamble (alternating 1s and 0s) and start frame delimiter, fetches the destination address and length field from the Transmit command, inserts its unique address as the source address, fetches the data field specified by the Transmit command, and computes and appends the CRC to the end of the frame (see Figure 12). In the Linear and 32-bit Segmented mode the CRC can be optionally inserted on a frame-by-frame basis by setting the NC bit in the Transmit Command Block (see Figures 29 and 30).

The 82596 can be configured to generate two types of start and end frame delimiters—End of Carrier (EOC) or HDLC. In EOC mode the start frame delimiter is 10101011 and the end frame delimiter is indicated by the lack of a signal after the last bit of the frame check sequence field has been transmitted. In EOC mode the 82596 can be configured to extend short frames by adding pad bytes (7Eh) during transmission, according to the length field. In HDLC mode the 82596 will generate the 01111110 flag for the start and end frame delimiters, and do standard bit stuffing and stripping. Furthermore, the 82596 can be configured to pad frames shorter than the specified minimum frame length by appending the appropriate number of flags to the end of the frame.

When a collision occurs, the 82596 manages the jam, random wait, and retry processes, reinitializing DMA pointers without CPU intervention. Multiple frames can be sent by linking the appropriate number of Transmit commands together. This is particularly useful when transmitting a message larger than the maximum frame size (1518 bytes for Ethernet).

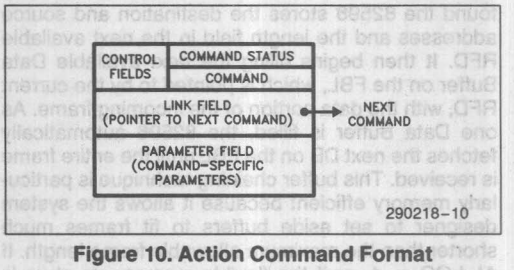


Figure 10. Action Command Format

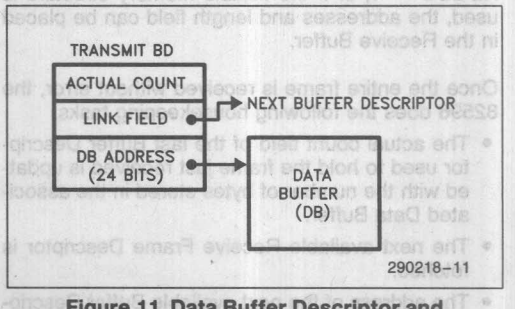


Figure 11. Data Buffer Descriptor and Data Buffer Structure

PREAMBLE	START FRAME DELIMITER	DESTINATION ADDRESS	SOURCE ADDRESS	LENGTH FIELD	DATA FIELD	FRAME CHECK SEQUENCE	END FRAME DELIMITER

Figure 12. Frame Format

RECEIVING FRAMES

To reduce CPU overhead, the 82596 is designed to receive frames without CPU supervision. The host CPU first sets aside an adequate receive buffer space and then enables the 82596 Receive Unit. Once enabled, the RU watches for arriving frames and automatically stores them in the Receive Frame Area (RFA). The RFA contains Receive Frame Descriptors, Receive Buffer Descriptors, and Data Buffers (see Figure 13). The individual Receive Frame Descriptors make up a Receive Descriptor List (RDL) used by the 82596 to store the destination and source addresses, the length field, and the status of each frame received (see Figure 14).

Once enabled, the 82596 checks each passing frame for an address match. The 82596 will recognize its own unique address, one or more multicast addresses, or the broadcast address. If a match is found the 82596 stores the destination and source addresses and the length field in the next available RFD. It then begins filling the next available Data Buffer on the FBL, which is pointed to by the current RFD, with the data portion of the incoming frame. As one Data Buffer is filled, the 82596 automatically fetches the next DB on the FBL until the entire frame is received. This buffer chaining technique is particularly memory efficient because it allows the system designer to set aside buffers to fit frames much shorter than the maximum allowable frame length. If AL-LOC = 1, or if the flexible memory structure is used, the addresses and length field can be placed in the Receive Buffer.

Once the entire frame is received without error, the 82596 does the following housekeeping tasks.

- The actual count field of the last Buffer Descriptor used to hold the frame just received is updated with the number of bytes stored in the associated Data Buffer.
- The next available Receive Frame Descriptor is fetched.
- The address of the next available Buffer Descriptor is written to the next available Receive Frame Descriptor.
- A frame received interrupt status bit is posted in the SCB.
- An interrupt is sent to the CPU.

If a frame error occurs, for example a CRC error, the 82596 automatically reinitializes its DMA pointers and reclaims any data buffers containing the bad frame. The 82596 will continue to receive frames without CPU help as long as Receive Frame Descriptors and Data Buffers are available.

82596 NETWORK MANAGEMENT AND DIAGNOSTICS

The behavior of data communication networks is normally very complex because of their distributed and asynchronous nature. It is particularly difficult to pinpoint a failure when it occurs. The 82596 has extensive diagnostic and network management functions that help improve reliability and testability. The 82596 reports on the following events after each frame is transmitted.

- Transmission successful.
- Transmission unsuccessful. Lost Carrier Sense.
- Transmission unsuccessful. Lost Clear to Send.
- Transmission unsuccessful. A DMA underrun occurred because the system bus did not keep up with the transmission.
- Transmission unsuccessful. The number of collisions exceeded the maximum allowed.
- Number of Collisions. The number of collisions experienced during the frame.
- Heartbeat Indicator. This indicates the presence of a heartbeat during the last Interframe Spacing (IFS) after transmission.

When configured to Save Bad Frames the 82596 checks each incoming frame and reports the following errors.

- CRC error. Incorrect CRC in a properly aligned frame.
- Alignment error. Incorrect CRC in a misaligned frame.
- Frame too short. The frame is shorter than the value configured for minimum frame length.
- Overrun. Part of the frame was not placed in memory because the system bus did not keep up with incoming data.
- Out of buffer. Part of the frame was discarded because of insufficient memory storage space.
- Receive collision. A collision was detected during reception.
- Length error. A frame not matching the frame length parameter was detected.

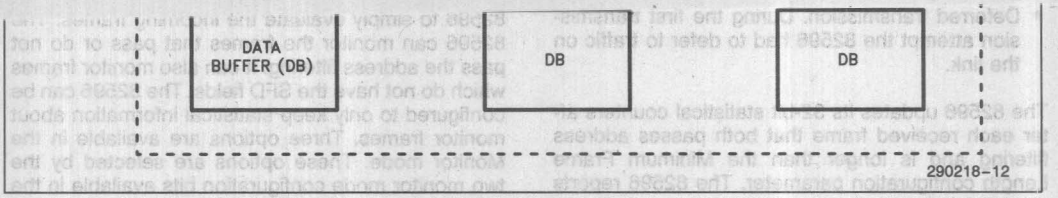


Figure 13. Receive Frame Area Diagram

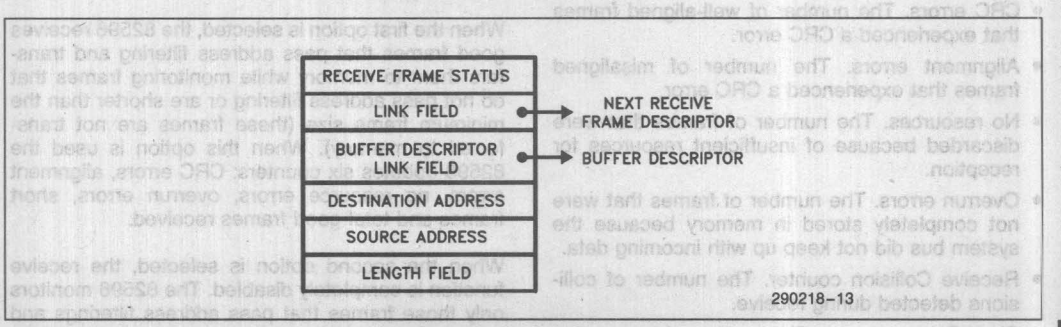


Figure 14. Receive Frame Descriptor

NETWORK PLANNING AND MAINTENANCE

To properly plan, operate, and maintain a communication network, the network management entity must accumulate information on network behavior. The 82596 provides a rich set of network-wide diagnostics that can serve as the basis for a network management entity.

Information on network activity is provided in the status of each frame transmitted. The 82596 reports the following activity indicators after each frame.

- Number of collisions. The number of collisions the 82596 experienced while attempting to transmit the frame.
- Deferred transmission. During the first transmission attempt the 82596 had to defer to traffic on the link.

The 82596 updates its 32-bit statistical counters after each received frame that both passes address filtering and is longer than the Minimum Frame Length configuration parameter. The 82596 reports the following statistics.

- CRC errors. The number of well-aligned frames that experienced a CRC error.
- Alignment errors. The number of misaligned frames that experienced a CRC error.
- No resources. The number of frames that were discarded because of insufficient resources for reception.
- Overrun errors. The number of frames that were not completely stored in memory because the system bus did not keep up with incoming data.
- Receive Collision counter. The number of collisions detected during receive.
- Short Frame counter. The number of frames that were discarded because they were shorter than the configured minimum frame length.

The 82596 can be configured to Promiscuous mode. In this mode it captures all frames transmitted on the network without checking the Destination Address. This is useful when implementing a monitoring station to capture all frames for analysis.

A useful method of capturing frame headers is to use the Simplified memory mode, configure the 82596 to Save Bad Frames, and configure the 82596 to Promiscuous mode with space in the RFD allocated for specific number of receive data bytes. The 82596 will receive all frames and put them in the RFD. Frames that exceed the available space in the RFD will be truncated, the status will be updated, and the 82596 will retrieve the next RFD. This allows the user to capture the initial data bytes of each frame (for instance, the header) and discard the remainder of the frame.

The 82596 also has a monitor mode for network analysis. During normal operation the receive function enables the 82596 to receive frames that pass address filtering. These frames must have the Start of Frame Delimiter (SFD) field and must be longer than the absolute minimum frame length of 5 bytes (6 bytes in case of Multicast address filtering). Contents and status of the received frames are transferred to memory. The monitor function enables the 82596 to simply evaluate the incoming frames. The 82596 can monitor the frames that pass or do not pass the address filtering. It can also monitor frames which do not have the SFD fields. The 82596 can be configured to only keep statistical information about monitor frames. Three options are available in the Monitor mode. These options are selected by the two monitor mode configuration bits available in the configuration command.

When the first option is selected, the 82596 receives good frames that pass address filtering and transfers them to memory while monitoring frames that do not pass address filtering or are shorter than the minimum frame size (these frames are not transferred to memory). When this option is used the 82596 updates six counters: CRC errors, alignment errors, no resource errors, overrun errors, short frames and total good frames received.

When the second option is selected, the receive function is completely disabled. The 82596 monitors only those frames that pass address filterings and meet the minimum frame length requirement. When this option is used the 82596 updates six counters: CRC errors, alignment errors, total frames (good and bad), short frames, collisions detected and total good frames.

When the third option is selected, the receive function is completely disabled. The 82596 monitors all frames, including frames that do not have a Start Frame Delimiter. When this option is used the 82596 updates six counters: CRC errors, alignment errors, total frames (good and bad), short frames, collisions detected and total good frames.

STATION DIAGNOSTICS AND SELF-TEST

The 82596 provides a large set of diagnostic and network management functions. These include internal and external loopback and time domain reflectometry for locating fault points in the network cable. The 82596 ensures software reliability by dumping the contents of the 82596 internal registers into system memory. The 82596 has a self-test mode that enables it to run an internal self-test and place the results in system memory.

82586 SOFTWARE COMPATIBILITY

The 82596 has a software-compatible state in which all its memory structures are compatible with the 82586 memory structure. This includes all the Action Commands, the Receive Frame Area (including the RFD, Buffer Descriptors, and Data Buffers), the System Control Block, and the initialization procedures. There are two minor differences between the 82596 in the 82586-Compatible memory structure and the 82586.

- When the internal and external loopback bits in the Configure command are set to 11 the 82596 is in external loopback and the $\overline{\text{LPBK}}$ pin is activated; in the 82586 this situation would produce internal loopback.
- During a Dump command both the 82596 and 82586 dump the same number of bytes; however, the data format is different.

INITIALIZING THE 82596

A Reset command is issued to the 82596 to prepare it for normal operation. The 82596 is initialized through two data structures that are addressed by two pointers, the System Configuration Pointer (SCP) and the Intermediate System Configuration Pointer (ISCP). The initialization procedure begins when a Channel Attention signal is asserted after RESET. The 82596 uses the address of the double word that contains the SCP as a default—00FFFFF4h. Before the CA signal is asserted this default address can be changed to any other available address by asserting the $\overline{\text{PORT}}$ pin and providing the desired address over the $D_{31}-D_4$ pins of the address bus. Pins D_3-D_0 must be 0010; i.e., any alternative address must be aligned to 16-byte boundaries. All addresses sent to the 82596 must be word aligned, which means that all pointers and memory structures must start on an even address (A_0 = zero).

SYSTEM CONFIGURATION POINTER (SCP)

The SCP contains the sysbus byte and the location of the next structure of the initialization process, the ISCP. The following parameters are selected in the SYSBUS.

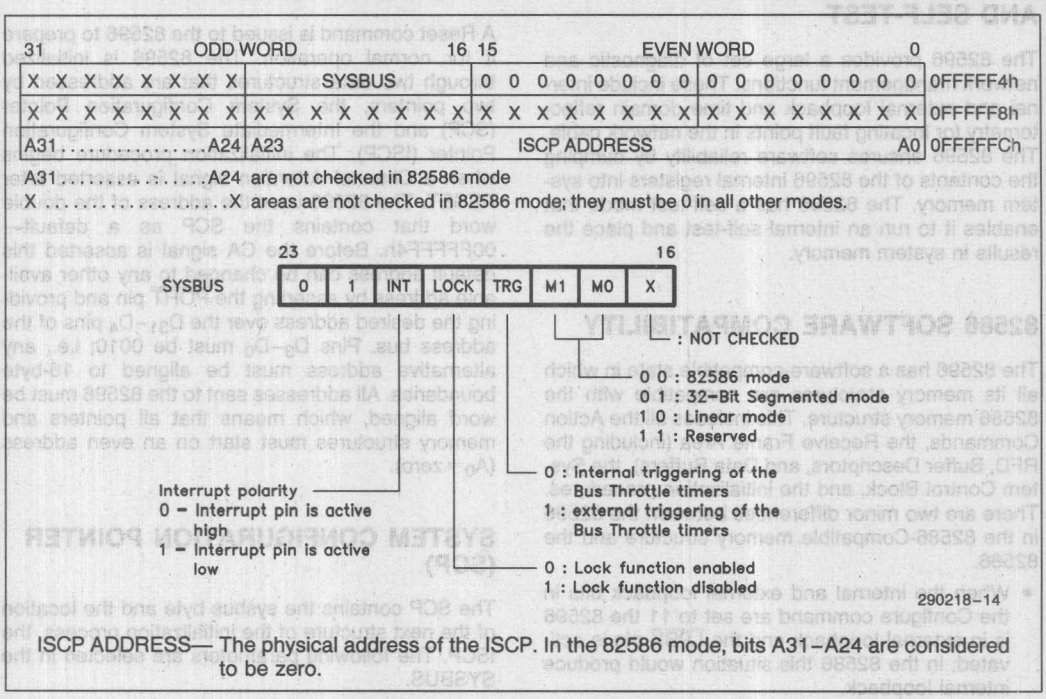
- The 82596 operation mode.
- The Bus Throttle timer triggering method.
- Lock enabled.
- Interrupt polarity.

Byte ordering is determined by the LE/$\overline{\text{BE}}$ pin. LE/$\overline{\text{BE}}$ = 1 selects Little Endian byte ordering and LE/$\overline{\text{BE}}$ = 0 selects Big Endian byte ordering.

NOTE:
In the following, X indicates a bit not checked 82586 mode. This bit must be set to 0 in all other modes.

7

The following diagram illustrates the format of the SCP.



ISCP ADDRESS— The physical address of the ISCP. In the 82586 mode, bits A31–A24 are considered to be zero.

Figure 15. The System Configuration Pointer

Writing the Sysbus

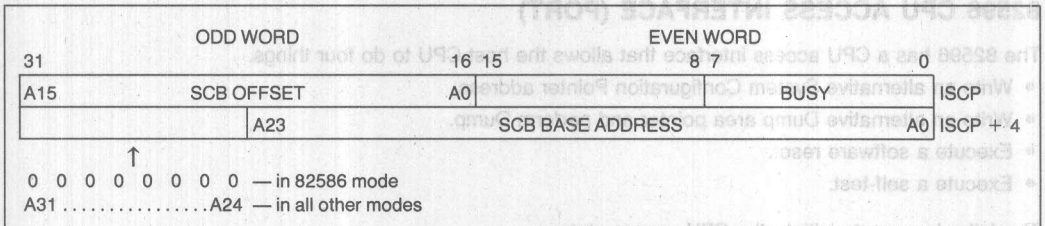
When writing the sysbus byte it is important to pay attention to the byte order.

- When a Little Endian processor is used, the sysbus byte is located at byte address 00FFFFF6h (or address $n+2$ if an alternative SCP address n was programmed).
- When a processor using Big Endian byte ordering is used, the sysbus, alternative SCP, and ISCP addresses will be different.
  - The sysbus byte is located at 00FFFFF5h.
  - If an alternative SCP address is programmed, the sysbus byte should be at byte address $n+1$.

INTERMEDIATE SYSTEM CONFIGURATION POINTER (ISCP)

The ISCP indicates the location of the System Control Block. Often the SCP is in ROM and the ISCP is in RAM. The CPU loads the SCB address (or an equivalent data structure) into the ISCP and asserts CA. This Channel Attention signal causes the 82596 to begin its initialization procedure and to get the SCB address from the ISCP and SCP. In 82586 and 32-bit Segmented modes the SCP base address is also the base address of all Command Blocks, Frame Descriptors, and Buffer Descriptors (but not buffers). All these data structures must reside in one 64-KB segment; however, in Linear mode no such limitation is imposed.

The following diagram illustrates the ISCP format.

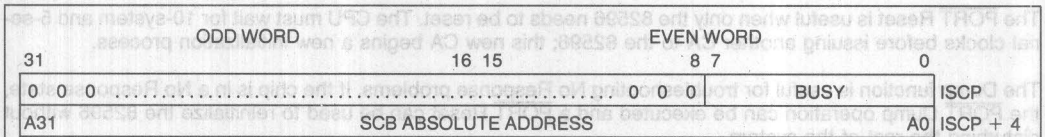


BUSY — Indicates that the 82596 is being initialized. The CPU sets the ISCP to 01h before it gives the first CA to the 82596. The ISCP is cleared by the 82596 after the SCB base and offset are read. Note that the most significant byte of the first word of the ISCP is not modified when BUSY is cleared.

SCB OFFSET— This 16-bit quantity specifies the offset portion of the address of the SCB.

SCB BASE — Specifies the base portion of the address of the SCB. The base of SCB is also the base of all 82596 Command Blocks, Frame Descriptors and Buffer Descriptors. In the 82586 mode, bits A31–A24 are considered to be zero.

Figure 16. The Intermediate System Configuration Pointer—82586 and 32-Bit Segmented Modes



BUSY — Indicates that the 82596 is being initialized. The ISCP is set to 01h by the CPU before its first CA to the 82596. It is cleared by the 82596 after the SCB address is read.

SCB ADDRESS— This 32-bit quantity specifies the physical address of the SCB.

Figure 17. The Intermediate System Configuration Pointer—Linear Mode.

INITIALIZATION PROCESS

The CPU sets up the SCP, ISCP, and the SCB structures, and, if desired, an alternative SCP address. It also sets BUSY to 01h. The 82596 is initialized when a Channel Attention signal follows a Reset signal, causing the 82596 to access the System Configuration Pointer. The sysbus byte, the operational mode, the bus throttle timer triggering method, the interrupt polarity, and the state of $\overline{LOCK}$ are read. After reset the Bus Throttle timers are essentially disabled—the T-ON value is infinite, the T-OFF value is zero. After the SCP is read, the 82596 reads the ISCP and saves the SCB address. In 82586 and 32-bit Segmented modes this address is represented as a base address plus the offset (this base address is also the base address of all the control blocks). In Linear mode the base address is also an absolute address. The 82596 clears BUSY, sets CX and CNR to equal 1 in the SCB, clears the SCB command word, sends an interrupt to the CPU, and awaits another Channel Attention signal. RESET configures the 82596 to its default state before CA is asserted.

CONTROLLING THE 82596CA

The host CPU controls the 82596 with the commands, data structures, and methods described in this section. The CPU and the 82596 communicate through shared memory structures. The 82596 contains two independent units: the Command Unit and the Receive Unit. The Command Unit executes commands from the CPU, and the Receive Unit handles frame reception. These two units are controlled and monitored by the CPU through a shared memory structure called the System Control Block (SCB). The CPU and the 82596 use the CA and INT signals to communicate with the SCB.

82596 CPU ACCESS INTERFACE ($\overline{PORT}$)

The 82596 has a CPU access interface that allows the host CPU to do four things.

- Write an alternative System Configuration Pointer address.
- Write an alternative Dump area pointer and perform Dump.
- Execute a software reset.
- Execute a self-test.

The following events initiate the CPU access state.

- Presence of an address on the $D_{31}-D_4$ data bus pins.
- The D_3-D_0 pins are used to select one of the four functions.
- The $\overline{PORT}$ input pin is asserted, as in a regular write cycle.

NOTE.
The SCP Dump and Self-Test addresses must be 16-byte aligned.

The 82596 requires two 16-bit write cycles for a port command. The first write holds the internal machines and reads the first 16 bits; the second activates the $\overline{PORT}$ command and reads the second 16 bits.

The $\overline{PORT}$ Reset is useful when only the 82596 needs to be reset. The CPU must wait for 10-system and 5-serial clocks before issuing another CA to the 82596; this new CA begins a new initialization process.

The Dump function is useful for troubleshooting No Response problems. If the chip is in a No Response state, the $\overline{PORT}$ Dump operation can be executed and a $\overline{PORT}$ Reset can be used to reinitialize the 82596 without disturbing the rest of the system.

The Self-Test function can be used for board testing; the 82596 will execute a self-test and write the results to memory.

Table 2. $\overline{PORT}$ Function Selection

Function	D31 ..... D4			D3	D2	D1	D0
	Addresses and Results						
Reset	A31	Don't Care	A4	0	0	0	0
Self-Test	A31	Self-Test Results Address	A4	0	0	0	1
SCP	A31	Alternative SCP Address	A4	0	0	1	0
Dump	A31	Dump Area Pointer	A4	0	0	1	1

MEMORY ADDRESSING FORMATS

The 82596 accesses memory by 32-bit addresses. There are two types of 32-bit addresses: linear and segmented. The type of address used depends on the 82596 operating mode and the type of memory structure it is addressing. The 82596 has three operating modes.

- 82586 Mode
  - A Linear address is a single 24-bit entity. Address pins A_{31}–A_{24} are always zero.
  - A Segmented address uses a 24-bit base and a 16-bit offset.
- 32-bit Segmented Mode
  - A Linear address is a single 32-bit entity.
  - A Segmented address uses a 32-bit base and a 16-bit offset.

NOTE

In the previous two memory addressing modes, each command header (CB, TBD, RFD, RBD, and SCB) must wholly reside within one segment. If the 82596 encounters a memory structure that does not follow this restriction, the 82596 will fetch the next contiguous location in memory (beyond the segment).

- Linear Mode
  - A Linear address is a single 32-bit entity.
  - There are no Segmented addresses.

Linear addresses are primarily used to address transmit and receive data buffers. In the 82586 and 32-bit Segmented modes, segmented addresses (base plus offset) are used for all Command Blocks, Buffer Descriptors, Frame Descriptors, and System Control Blocks. When using Segmented addresses, only the offset portion of the entity being addressed is specified in the block. The base for all offsets is the same—that of the SCB. See Table 1.

LITTLE ENDIAN AND BIG ENDIAN BYTE ORDERING

The 82596 supports both Little Endian and Big Endian byte ordering for its memory structures.

The 82596 supports Big Endian byte ordering for word and byte entities. Dword entities are not supported with Big Endian byte ordering. This results in slightly different 82596 memory structures for Big Endian operation. These structures are defined in the *82596 User's Manual*.

NOTE

All 82596 memory entities must be word or dword aligned.

An example of a dword entity is a frame descriptor command/status dword, whereas the raw data of the frame are byte entities. Both 32- and 16-bit buses are supported. When a 16-bit bus is used with Big Endian memory organization, data lines D_{15}–D_0 are used. The 82596 has an internal crossover that handles these swap operations.

COMMAND UNIT (CU)

The Command Unit is the logical unit that executes Action Commands from a list of commands very similar to a CPU program. A Command Block is associated with each Action Command. The CU is modeled as a logical machine that takes, at any given time, one of the following states.

- **Idle.** The CU is not executing a command and is not associated with a CB on the list. This is the initial state.
- **Suspended.** The CU is not executing a command; however, it is associated with a CB on the list.
- **Active.** The CU is executing an Action Command and pointing to its CB.

The CPU can affect CU operation in two ways: by issuing a CU Control Command or by setting bits in the Command word of the Action Command.

RECEIVE UNIT (RU)

The Receive Unit is the logical unit that receives frames and stores them in memory. The RU is modeled as a logical machine that takes, at any given time, one of the following states.

- **Idle.** The RU has no memory resources and is discarding incoming frames. This is the initial state.
- **No Resources.** The RU has no memory resources and is discarding incoming frames. This state differs from Idle in that the RU accumulates statistics on the number of discarded frames.
- **Suspended.** The RU has memory available for storing frames, but is discarding them. The suspend state can only be reached if the CPU forces this through the SCB or sets the suspend bit in the RFD.
- **Ready.** The RU has memory available and is storing incoming frames.

The CPU can affect RU operation in three ways: by issuing an RU Control Command, by setting bits in the Frame Descriptor Command word of the frame being received, or by setting the EL bit of the current buffer's Buffer Descriptor.

SYSTEM CONTROL BLOCK (SCB)

The SCB is a memory block that plays a major role in communications between the CPU and the 82596. Such communications include the following.

- Commands issued by the CPU
- Status reported by the 82596

Control commands are sent to the 82596 by writing them into the SCB and then asserting CA. The 82596 examines the command, performs the required action, and then clears the SCB command word. Control commands perform the following types of tasks.

- Operation of the Command Unit (CU). The SCB controls the CU by specifying the address of the Command Block List (CBL) and by starting, suspending, resuming, or aborting execution of CBL commands.
- Operation of the Bus Throttle. The SCB controls the Bus Throttle timers by providing them with new values and sending the Load and Start timer commands. The timers can be operated in both the 32-bit Segmented and Linear modes.
- Reception of frames by the Receive Unit (RU). The SCB controls the RU by specifying the address of the Receive Frame Area and by starting, suspending, resuming, or aborting frame reception.
- Acknowledgment of events that cause interrupts.
- Resetting the chip.

The 82596 sends status reports to the CPU via the System Control Block. The SCB contains four types of status reports.

- The cause of the current interrupts. These interrupts are caused by one or more of the following 82596 events.
  - The Command Unit completes an Action Command that has its I bit set.
  - The Receive Unit receives a frame.
  - The Command Unit becomes inactive.
  - The Receive Unit becomes not ready.
- The status of the Command Unit.
- The status of the Receive Unit.
- Status reports from the 82596 regarding reception of corrupted frames.

Events can be cleared only by CPU acknowledgment. If some events are not acknowledged by the ACK field the Interrupt signal (INT) will be reissued after Channel Attention (CA) is processed. Furthermore, if a new event occurs while an interrupt is set, the interrupt is temporarily cleared to trigger edge-triggered interrupt controllers.

The CPU uses the Channel Attention line to cause the 82596 to examine the SCB. This signal is trailing-edge triggered—the 82596 latches CA on the trailing edge. The latch is cleared by the 82596 before the SCB control command is read.

31 ODD WORD 16	15 EVEN WORD 0	
ACK X CUC R RUC X X X X	STAT 0 CUS 0 RUS 0 0 0 0	SCB
RFA OFFSET	CBL OFFSET	SCB + 4
ALIGNMENT ERRORS	CRC ERRORS	SCB + 8
OVERRUN ERRORS	RESOURCE ERRORS	SCB + 12

Figure 18. SCB—82586 Mode

31 ODD WORD 16	15 EVEN WORD 0	
ACK 0 CUC R RUC 0 0 0 0	STAT 0 CUS RUS T 0 0 0	SCB
RFA OFFSET	CBL OFFSET	SCB + 4
CRC ERRORS		SCB + 8
ALIGNMENT ERRORS		SCB + 12
RESOURCE ERRORS (*)		SCB + 16
OVERRUN ERRORS (*)		SCB + 20
RCVCDT ERRORS (*)		SCB + 24
SHORT FRAME ERRORS		SCB + 28
T-ON TIMER	T-OFF TIMER	SCB + 32

*In monitor mode these counters change function

Figure 19. SCB—32-Bit Segmented Mode

31 ODD WORD 16	15 EVEN WORD 0	
ACK 0 CUC R RUC 0 0 0 0	STAT 0 CUS RUS T 0 0 0	SCB
COMMAND BLOCK ADDRESS		SCB + 4
RECEIVE FRAME AREA ADDRESS		SCB + 8
CRC ERRORS		SCB + 12
ALIGNMENT ERRORS		SCB + 16
RESOURCE ERRORS (*)		SCB + 20
OVERRUN ERRORS (*)		SCB + 24
RCVCDT ERRORS (*)		SCB + 28
SHORT FRAME ERRORS		SCB + 32
T-ON TIMER	T-OFF TIMER	SCB + 36

*In MONITOR mode these counters change function

Figure 20. SCB—Linear Mode

Command Word

31				16					
ACK	0	CUC	R	RUC	0	0	0	0	SCB + 2

These bits specify the action to be performed as a result of a CA. This word is set by the CPU and cleared by the 82596. Defined bits are:

Bit 31 ACK-CX — Acknowledges that the CU completed an Action Command.

Bit 30 ACK-FR — Acknowledges that the RU received a frame.

Bit 29 ACK-CNA — Acknowledges that the Command Unit became not active.

Bit 28 ACK-RNR — Acknowledges that the Receive Unit became not ready.

Bits 24–26 CUC — (3 bits) This field contains the command to the Command Unit. Valid values are:

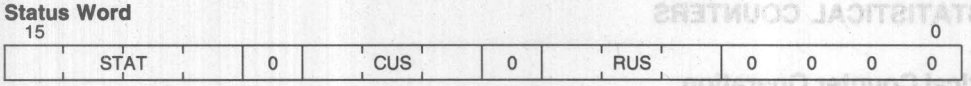
- 0 — NOP (does not affect current state of the unit).
- 1 — Start execution of the first command on the CBL. If a command is executing, complete it before starting the new CBL. The beginning of the CBL is in CBL OFFSET (address).
- 2 — Resume the operation of the Command Unit by executing the next command. This operation assumes that the Command Unit has been previously suspended.
- 3 — Suspend execution of commands on CBL after current command is complete.
- 4 — Abort current command immediately.
- 5 — Loads the Bus Throttle timers so they will be initialized with their new values after the active timer (T-ON or T-OFF) reaches Terminal Count. If no timer is active new values will be loaded immediately. This command is not valid in 82586 mode.
- 6 — Loads and immediately restarts the Bus Throttle timers with their new values. This command is not valid in 82586 mode.
- 7 — Reserved.

Bit 23 RESET — Reset chip (logically the same as hardware RESET).

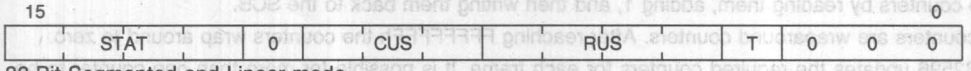
Bits 20–22 RUC — (3 bits) This field contains the command to the Receive Unit. Valid values are:

- 0 — NOP (does not alter current state of unit).
- 1 — Start reception of frames. The beginning of the RFA is contained in the RFA OFFSET (address). If a frame is being received complete reception before starting.
- 2 — Resume frame reception (only when in suspended state).
- 3 — Suspend frame reception. If a frame is being received complete its reception before suspending.
- 4 — Abort receiver operation immediately.
- 5–7 — Reserved.

Status Word



82586 mode



32-Bit Segmented and Linear mode.

Indicates the status of the 82596. This word is modified only by the 82596. Defined bits are:

Bit 15 CX — The CU finished executing a command with its I (interrupt) bit set.

Bit 14 FR — The RU finished receiving a frame.

Bit 13 CNA — The Command Unit left the Active state.

Bit 12 RNR — The Receive Unit left the Ready state.

Bits 8–10 CUS — (3 bits) This field contains the status of the command unit. Valid values are:

0 — Idle

1 — Suspended

2 — Active

3–7 — Not used

Bits 4–7 RUS — This field contains the status of the receive unit. Valid values are:

0h (0000) — Idle

1h (0001) — Suspended

2h (0010) — No Resources. This bit indicates both no resources due to lack of RFDs in the RDL and no resources due to lack of RBDs in the FBL.

4h (0100) — Ready

8h (1000) — No more RBDs (not in the 82586 mode)

Ah (1010) — No resources due to no more RBDs (not in the 82586 mode).

No other combinations are allowed

Bit 3 T — Bus Throttle timers loaded (not in 82586 mode).

SCB OFFSET ADDRESSES

CBL Offset (Address)

In 82586 and 32-bit Segmented modes this 16-bit quantity indicates the offset portion of the address for the first Command Block on the CBL. In Linear mode it is a 32-bit linear address for the first Command Block on the CBL. It is accessed only if CUC equals Start.

RFA Offset (Address)

In 82586 and 32-bit Segmented modes this 16-bit quantity indicates the offset portion of the address for the Receive Frame Area. In Linear mode it is a 32-bit linear address for the Receive Frame Area. It is accessed only if RUC equals Start.

SCB STATISTICAL COUNTERS

Statistical Counter Operation

- The CPU is responsible for clearing all error counters before initializing the 82596. The 82596 updates these counters by reading them, adding 1, and then writing them back to the SCB.
- The counters are wraparound counters. After reaching FFFFFFFFh the counters wrap around to zero.
- The 82596 updates the required counters for each frame. It is possible for more than one counter to be updated; multiple errors will result in all affected counters being updated.
- The 82596 executes the read-counter/increment/write-counter operation without relinquishing the bus (locked operation). This is to ensure that no logical contention exists between the 82596 and the CPU due to both attempting to write to the counters simultaneously. In the dual-port memory configuration the CPU should not execute any write operation to a counter if $\overline{LOCK}$ is asserted.
- The counters are 32-bits wide and their behavior is fully compatible with the IEEE 802.3 standard. The 82596 supports all relevant statistics (mandatory, optional, and desired) through the status of the transmit and receive header and directly through SCB statistics.

CRCERRS

This 32-bit quantity contains the number of aligned frames discarded because of a CRC error. This counter is updated, if needed, regardless of the RU state.

ALNERRS

This 32-bit quantity contains the number of frames that both are misaligned (i.e., where $\overline{CRS}$ deasserts on a nonoctet boundary) and contain a CRC error. The counter is updated, if needed, regardless of the RU state.

SHRTFRM

This 32-bit quantity contains the number of received frames shorter than the minimum frame length.

The last three counters change function in monitor mode.

RSCERRS

This 32-bit quantity contains the number of good frames discarded because there were no resources to contain them. Frames intended for a host whose RU is in the No Receive Resources state, fall into this category. This counter is updated only if the RU is in the No Resources state. When in Monitor mode this counter counts the total number of frames—good and bad.

OVRNERRS

This 32-bit quantity contains the number of frames known to be lost because the local system bus was not available. If the traffic problem lasts longer than the duration of one frame, the frames that follow the first are lost without an indicator, and they are not counted. This counter is updated, if needed, regardless of the RU state.

RCVCDT

This 32-bit quantity contains the number of collisions detected during frame reception. In Monitor mode this counter counts the total number of good frames.

ACTION COMMANDS AND OPERATING MODES

This section lists all the Action Commands of the Command Unit Command Block List (CBL). Each command contains the Command field, the Status and Control fields, the link to the next Action Command, and any command-specific parameters. There are three basic types of action commands: 82596 Configuration and Setup, Transmission, and Diagnostics. The following is a list of the actual commands.

- NOP
- Individual Address Setup
- Configure
- MC Setup
- Transmit
- TDR
- Dump
- Diagnose

The 82596 has three addressing modes. In the 82586 mode all the Action Commands look exactly like those of the 82586.

- **82586 Mode.** The 82596 software and memory structure is compatible with the 82586.
- **32-Bit Segmented Mode.** The 82596 can access the entire system memory and use the two new memory structures—Simplified and Flexible—while still using the segmented approach. This does not require any significant changes to existing software.
- **Linear Mode.** The 82596 operates in a flat, linear, 4 gigabyte memory space without segmentation. It can also use the two new memory structures.

In the 32-bit Segmented mode there are some differences between the 82596 and 82586 action commands, mainly in programming and activating new 82596 features. Those bits marked "don't care" in the compatible mode are not checked; however, we strongly recommend that those bits all be zeroes; this will allow future enchancements and extensions.

In the Linear mode all of the address offsets become 32-bit address pointers. All new 82596 features are accessible in this mode, and all bits previously marked "don't care" must be zeroes.

The Action Commands, and all other 82596 memory structures, must begin on even byte boundaries, i.e., they must be word aligned.

NOP

This command results in no action by the 82596 except for those performed in the normal command processing. It is used to manipulate the CBL manipulation. The format of the NOP command is shown in Figure 21.

NOP—82586 and 32-Bit Segmented Modes

31			ODD WORD														16	15			EVEN WORD														0	
EL	S	I	X	X	X	X	X	X	X	X	X	X	0	0	0	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	A15																		A0	4

NOP—Linear Mode

31			ODD WORD														16	15			EVEN WORD														0	
EL	S	I	0	0	0	0	0	0	0	0	0	0	0	0	0	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A31																																			A0	4

Figure 21

where:

LINK POINTER — In the 82586 or 32-bit Segmented modes this is a 16-bit offset to the next Command Block. In the Linear mode this is the 32-bit address of the next Command Block.

EL — If set, this bit indicates that this command block is the last on the CBL.

S — If set to one, suspend the CU upon completion of this CB.

I — If set to one, the 82596 will generate an interrupt after execution of the command is complete. If I is not set to one, the CX bit will not be set.

CMD (bits 16–18) — The NOP command. Value: 0h.

Bits 19–28 — Reserved (zero in the 32-bit Segmented and Linear modes).

C — This bit indicates the execution status of the command. The CPU initially resets it to zero when the Command Block is placed on the CBL. Following a command Completion, the 82596 will set it to one.

B — This bit indicates that the 82596 is currently executing the NOP command. It is initially reset to zero by the CPU. The 82596 sets it to one when execution begins and to zero when execution is completed. This bit is also set when the 82596 prefetches the command.

NOTE:

The C and B bits are modified in one operation.

OK — Indicates that the command was executed without error. If set to one no error occurred (command executed OK). If zero an error occured.

Individual Address Setup

This command is used to load the 82596 with the Individual Address. This address is used by the 82596 for inserting the Source Address during transmission and recognizing the Destination Address during reception. After RESET, and prior to Individual Address Setup Command execution, the 82596 assumes the Broadcast Address is the Individual Address in all aspects, i.e.:

- This will be the Individual Address Match reference.
- This will be the Source Address of a transmitted frame (for AL-LOC = 0 mode only).

The format of the Individual Address Setup command is shown in Figure 22.

IA Setup—82586 and 32-Bit Segmented Modes

31	ODD WORD	16 15	EVEN WORD	0	
EL S I X X X X X X X X X X 0 0 1		C B OK A	0 0 0 0 0 0 0 0 0 0 0 0		0
INDIVIDUAL ADDRESS	1st byte	A15	LINK OFFSET	A0	4
6th byte	5th byte	4th byte	3rd byte		8

IA Setup—Linear Mode

31	ODD WORD	16 15	EVEN WORD	0	
EL S I 0 0 0 0 0 0 0 0 0 0 0 0 1		C B OK A	0 0 0 0 0 0 0 0 0 0 0 0		0
A31	LINK ADDRESS			A0	4
4th byte	3rd byte	INDIVIDUAL ADDRESS	1st byte		8
		6th byte	5th byte		C

Figure 22

where:

LINK ADDRESS, EL, B, C, I, S — As per standard Command Block (see the NOP command for details)

A — Indicates that the command was abnormally terminated due to CU Abort control command. If one, then the command was aborted, and if necessary it should be repeated. If this bit is zero, the command was not aborted.

Bits 19–28 — Reserved (zero in the 32-bit Segmented and Linear modes).

CMD (bits 16–18) — The Address Setup command. Value: 1h.

INDIVIDUAL ADDRESS — The individual address of the node, 0 to 6 bytes long.

The least significant bit of the Individual Address must be zero for Ethernet (see the Command Structure). However, no enforcement of 0 is provided by the 82596. Thus, an Individual Address with 1 as its least significant bit is a valid Individual Address in all aspects.

The default address length is 6 bytes long, as in 802.3. If a different length is used the IA Setup command should be executed after the Configure command.

Configure

The Configure command loads the 82596 with its operating parameters. It allows changing some of the parameters by specifying a byte count less than the maximum number of configuration bytes (12 in the 82586 mode, 16 in the 32-Bit Segmented and Linear modes). The 82596 configuration depends on its mode of operation.

- In the 82586 mode the maximum number of configuration bytes is 12. Any number larger than 12 will be reduced to 12 and any number less than 4 will be increased to 4.
- The additional features of the serial side are disabled in the 82586 mode.
- In both the 32-Bit Segmented and Linear modes there are four additional configuration bytes, which hold parameters for additional 82596 features. If these parameters are not accessed, the 82596 will follow their default values.
- For more detailed information refer to the 32-Bit LAN Components User's Manual.

The format of the Configure command is shown in Figure 23, 24 and 25.

31 ODD WORD 16	15 EVEN WORD 0	
EL S I X X X X X X X X X X 0 1 0	C B OK A 0 0 0 0 0 0 0 0 0 0 0 0	0
Byte 1 / Byte 0	A15 LINK OFFSET A0	4
Byte 5 / Byte 4	Byte 3 / Byte 2	8
Byte 9 / Byte 8	Byte 7 / Byte 6	12
X X X X X X X X X X X X X X X X	X X X X X X X X / Byte 10	16

Figure 23. CONFIGURE—82586 Mode

31 ODD WORD 16	15 EVEN WORD 0	
EL S I 0 0 0 0 0 0 0 0 0 0 0 1 0	C B OK A 0 0 0 0 0 0 0 0 0 0 0 0	0
Byte 1 / Byte 0	A15 LINK OFFSET A0	4
Byte 5 / Byte 4	Byte 3 / Byte 2	8
Byte 9 / Byte 8	Byte 7 / Byte 6	12
Byte 13 / Byte 12	Byte 11 / Byte 10	16

Figure 24. CONFIGURE—32-Bit Segmented Mode

31 ODD WORD 16	15 EVEN WORD 0	
EL S I 0 0 0 0 0 0 0 0 0 0 0 1 0	C B OK A 0 0 0 0 0 0 0 0 0 0 0 0	0
A31 LINK ADDRESS A0		4
Byte 3 / Byte 2	Byte 1 / Byte 0	8
Byte 7 / Byte 6	Byte 5 / Byte 4	12
Byte 11 / Byte 10	Byte 9 / Byte 8	16
X X X X X X X X X X X X X X X X	Byte 13 / Byte 12	20

Figure 25. CONFIGURE—Linear Mode

LINK ADDRESS, EL, B, C, I, S — As per standard Command Block (see the NOP command for details)

A — Indicates that the command was abnormally terminated due to a CU Abort control command. If 1, then the command was aborted and if necessary it should be repeated. If this bit is 0, the command was not aborted.

Bits 19–28 — Reserved (zero in the 32-Bit Segmented and Linear Modes)

CMD (bits 16–18) — The CONFIGURE command. Value: 2h.

The interpretation of the fields follows:

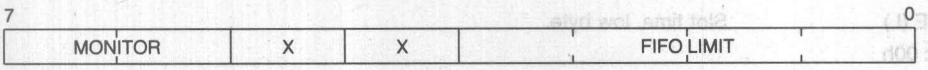
7	6	5	4	3 2 1 0
P	X	X	X	BYTE COUNT

BYTE 0

BYTE CNT (Bits 0–3) — Byte Count. Number of bytes, including this one, that hold parameters to be configured.

PREFETCHED (Bit 7) — Enable the 82596 to write the prefetched bit in all prefetch RBDs.

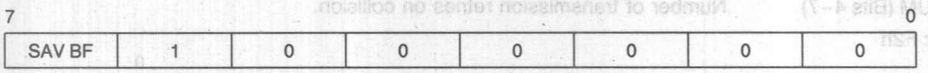
NOTE:
The P bit is valid only in the new memory structure modes. In 82586 mode this bit is disabled (i.e., no prefetched mark).



BYTE 1

FIFO Limit (Bits 0–3)	FIFO limit.
MONITOR# (Bits 6–7)	Receive monitor options. If the Byte Count of the configure command is less than 12 bytes then these Monitor bits are ignored.

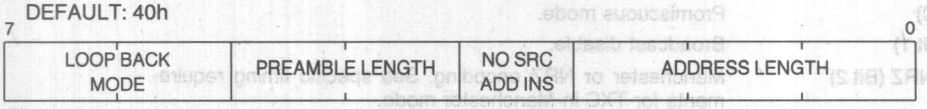
DEFAULT: C8h



BYTE 2

SAV BF (Bit 7)	0—Received bad frames are not saved in the memory. 1—Received bad frames are saved in the memory.

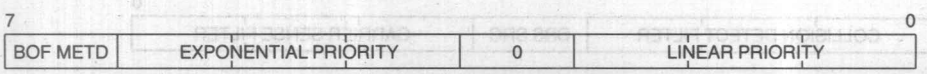
DEFAULT: 40h



BYTE 3

ADR LEN (Bits 0–2)	Address length (any kind).
NO SCR ADD INS (Bit 3)	No Source Address Insertion. In the 82586 this bit is called AL LOC.
PREAM LEN (Bits 4–5)	Preamble length.
LP BCK MODE (Bits 6–7)	Loopback mode.

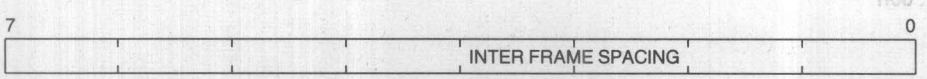
DEFAULT: 26h



BYTE 4

LIN PRIO (Bits 0–2)	Linear Priority.
EXP PRIO (Bits 4–6)	Exponential Priority.
BOF METD (Bit 7)	Exponential Backoff method.

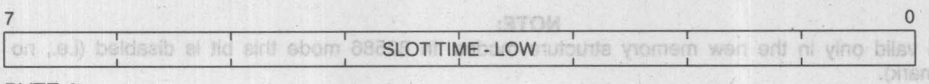
DEFAULT: 00h



BYTE 5

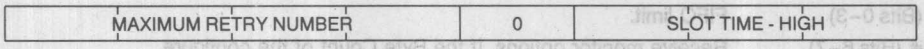
INTERFRAME SPACING	Interframe spacing.

DEFAULT: 60h



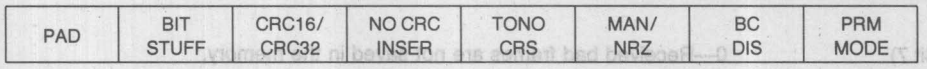
BYTE 6

SLOT TIME (L)	Slot time, low byte.
DEFAULT: 00h	



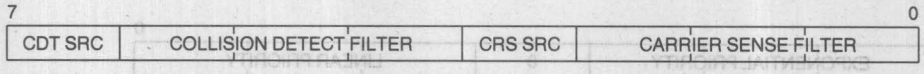
BYTE 7

SLOT TIME (H) (Bits 0–2)	Slot time, high part.
RETRY NUM (Bits 4–7)	Number of transmission retries on collision.
DEFAULT: F2h	



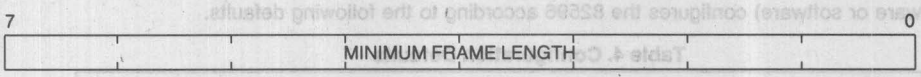
BYTE 8

PRM (Bit 0)	Promiscuous mode.
BC DIS (Bit 1)	Broadcast disable.
MANCH/NRZ (Bit 2)	Manchester or NRZ encoding. See specific timing requirements for TXC in Manchester mode.
TONO CRS (Bit 3)	Transmit on no CRS.
NOCRC INS (Bit 4)	No CRC insertion.
CRC-16/CRC-32 (Bit 5)	CRC type.
BIT STF (Bit 6)	Bit stuffing.
PAD (Bit 7)	Padding.
DEFAULT: 00h	



BYTE 9

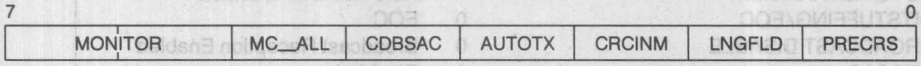
CRSF (Bits 0–2)	Carrier Sense filter (length).
CRS SRC (Bit 3)	Carrier Sense source.
CDTF (Bits 4–6)	Collision Detect filter (length).
CDT SRC (Bit 7)	Collision Detect source.
DEFAULT: 00h	



BYTE 10

MIN FRAME LEN — Minimum frame length.

DEFAULT: 40h



BYTE 11

PRECRS (Bit 0) — Preamble until Carrier Sense

LNGFLD (Bit 1) — Length field. Enables padding at the End-of-Carrier framing (802.3).

CRCINM (Bit 2) — Rx CRC appended to the frame in memory.

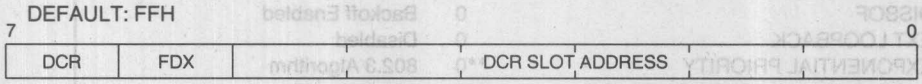
AUTOTX (Bit 3) — Auto retransmit when a collision occurs during the preamble.

CDBSAC (Bit 4) — Collision Detect by source address recognition.

MC_ALL (Bit 5) — Enable to receive all MC frames.

MONITOR (Bits 6–7) — Receive monitor options.

DEFAULT: FFH



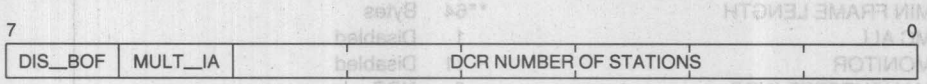
BYTE 12

DCR SLOT ADDRESS (Bits 0–5) — Station index in DCR mode.

FDX (Bit 6) — Enables Full Duplex operation.

DCR (Bit 7) — Enables Deterministic collision resolution.

DEFAULT: 00h



BYTE 13

DCR NUMBER OF STATIONS (Bits 0–5) — Number of stations in DCR mode.

MULT_IA (Bit 6) — Multiple individual address.

DIS_BOF (Bit 7) — Disable the backoff algorithm.

DEFAULT: 3Fh

7

A reset (hardware or software) configures the 82596 according to the following defaults.

Table 4. Configuration Defaults

	Parameter	Default Value	Units/Meaning
	ADDRESS LENGTH	**6	Bytes
	A/L FIELD LOCATION	0	Located in FD
*	AUTO RETRANSMIT	1	Auto Retransmit Enable
	BITSTUFFING/EOC	0	EOC
	BROADCAST DISABLE	0	Broadcast Reception Enabled
*	CDBSAC	1	Disabled
	CDT FILTER	0	Bit Times
	CDT SRC	0	External Collision Detection
*	CRC IN MEMORY	1	CRC Not Transferred to Memory
	CRC-16/CRC-32	**0	CRC-32
	CRS FILTER	0	0 Bit Times
	CRS SRC	0	External CRS
*	DCR	0	Disable DCR Protocol
*	DCR Slot Number	0	DCR Disabled
*	DCR Number of Stations	63	Stations
*	DISBOF	0	Backoff Enabled
	EXT LOOPBACK	0	Disabled
	EXPONENTIAL PRIORITY	**0	802.3 Algorithm
	EXPONENTIAL BACKOFF METHOD	**0	802.3 Algorithm
*	FULL DUPLEX (FDX)	0	CSMA/CD Protocol (No FDX)
	FIFO THRESHOLD	8	TX: 32 Bytes, RX: 64 Bytes
	INT LOOPBACK	0	Disabled
	INTERFRAME SPACING	**96	Bit Times
	LINEAR PRIORITY	**0	802.3 Algorithm
*	LENGTH FIELD	1	Padding Disabled
	MIN FRAME LENGTH	**64	Bytes
*	MC ALL	1	Disabled
*	MONITOR	11	Disabled
	MANCHESTER/NRZ	0	NRZ
*	MULTI IA	0	Disabled
	NUMBER OF RETRIES	**15	Maximum Number of Retries
	NO CRC INSERTION	0	CRC Appended to Frame
	PREFETCH BIT IN RBD	0	Disabled (Valid Only in New Modes)
	PREAMBLE LENGTH	**7	Bytes
*	Preamble Until CRS	1	Disabled
	PROMISCUOUS MODE	0	Address Filter On
	PADDING	0	No Padding
	SLOT TIME	**512	Bit Times
	SAVE BAD FRAME	0	Discards Bad Frames
	TRANSMIT ON NO CRS	0	Disabled

NOTES
1. This configuration setup is compatible with the IEEE 802.3 specification.
2. The Asterisk "*" signifies a new configuration parameter not available in the 82586.
3. The default value of the Auto retransmit configuration parameter is enabled(1).
4. Double Asterisk "**" signifies IEEE 802.3 requirements.

Multicast-Setup

This command is used to load the 82596 with the Multicast-IDs that should be accepted. As noted previously, the filtering done on the Multicast-IDs is not perfect and some unwanted frames may be accepted. This command resets the current filter and reloads it with the specified Multicast-IDs. The format of the Multicast-addresses setup command is:

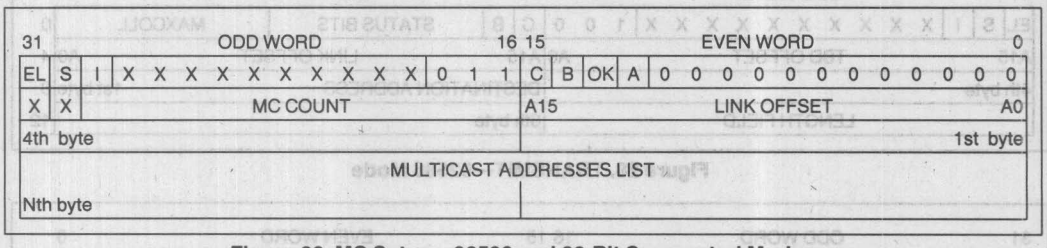


Figure 26. MC Setup—82586 and 32-Bit Segmented Modes

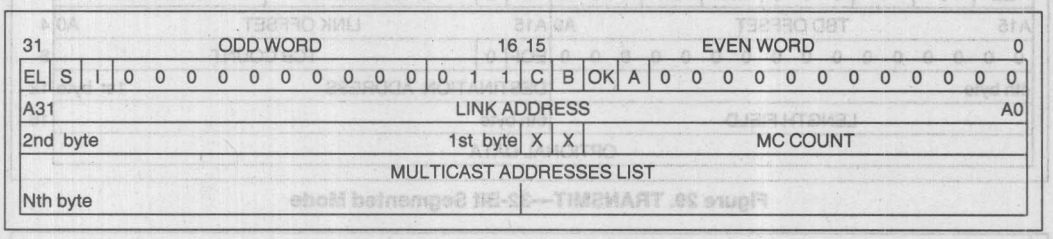


Figure 27. MC Setup—Linear Mode

where:

LINK ADDRESS, EL, B, C, I, S — As per standard Command Block (see the NOP command for details)

A — Indicates that the command was abnormally terminated due to a CU Abort control command. If one, then the command was aborted and if necessary it should be repeated. If this bit is zero, the command was not aborted.

Bits 19–28 — Reserved (0 in both the 32-Bit Segmented and Linear Modes).

CMD (bits 16–18) — The MC SETUP command value: 3h.

MC-CNT — This 14-bit field indicates the number of bytes in the MC LIST field. The MC CNT must be a multiple of the ADDR LEN; otherwise, the 82596 reduces the MC CNT to the nearest ADDR LEN multiple. MC CNT = 0 implies resetting the Hash table which is equivalent to disabling the Multicast filtering mechanism.

MC LIST — A list of Multicast Addresses to be accepted by the 82596. The least significant bit of each MC address must be 1.

NOTE:

The list is sequential; i.e., the most significant byte of an address is immediately followed by the least significant byte of the next address.

— When the 82596 is configured to recognize multiple Individual Address (Multi-IA), the MC-Setup command is also used to set up the Hash table for the individual address.

The least significant bit in the first byte of each IA address must be 0.

7

Transmit

This command is used to transmit a frame of user data onto the serial link. The format of a Transmit command is as follows.

31 ODD WORD 16	15 EVEN WORD 0	
EL S I X X X X X X X X X X 1 0 0	C B STATUS BITS MAXCOLL	0
A15 TBD OFFSET A0	A15 LINK OFFSET A0	4
4th byte	DESTINATION ADDRESS 1st byte	8
LENGTH FIELD	6th byte	12

Figure 28. TRANSMIT—82586 Mode

31 ODD WORD 16	15 EVEN WORD 0	
EL S I 0 0 0 NC SF 1 0 0	C B STATUS BITS MAXCOLL	0
A15 TBD OFFSET A0	A15 LINK OFFSET A0	4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	EOF 0 TCB COUNT	8
4th byte	DESTINATION ADDRESS 1st byte	12
LENGTH FIELD	6th byte	16
OPTIONAL DATA		

Figure 29. TRANSMIT—32-Bit Segmented Mode

31 ODD WORD 16	15 EVEN WORD 0	
EL S I 0 0 0 0 NC SF 1 0 0	C B STATUS BITS MAXCOLL	0
A31 LINK ADDRESS A0		4
A31 TRANSMIT BUFFER DESCRIPTOR ADDRESS A0		8
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	EOF 0 TCB COUNT	12
4th byte	DESTINATION ADDRESS 1st byte	16
LENGTH FIELD	6th byte	20
OPTIONAL DATA		

Figure 30. TRANSMIT—Linear Mode

31 COMMAND WORD 16	
EL S I 0 0 0 0 0 0 0 0 NC SF 1 0 0	2

0: No CRC Insertion disable; when the configure command is configured to not insert the CRC during transmission the NC bit has no effect.

1: No CRC Insertion enable; when the configure command is configured to insert the CRC during transmission the CRC will not be inserted when NC = 1.

0: Simplified Mode, all the Tx data is in the Transmit Command Block. The Transmit Buffer Descriptor Address field is all 1s.

1: Flexible Mode. Data is in the TCB and in a linked list of TBDs.

where:

EL, B, C, I, S — As per standard Command Block (see the NOP command for details).

OK (Bit 13) — Error free completion.

A (Bit 12) — Indicates that the command was abnormally terminated due to CU Abort control command. If 1, then the command was aborted, and if necessary it should be repeated. If this bit is 0, the command was not aborted.

Bits 19–28 — Reserved (0 in the 32-bit Segmented and Linear modes).

CMD (Bits 16–18) — The transmit command: 4h.

Status Bit 11 — Late collision. A late collision (a collision after the slot time is elapsed) is detected.

Status Bit 10 — No Carrier Sense signal during transmission. Carrier Sense signal is monitored from the end of Preamble transmission until the end of the Frame Check Sequence for TONOCRS = 1 (Transmit On No Carrier Sense mode) it indicates that transmission has been executed despite a lack of CRS. For TONOCRS = 0 (Ethernet mode), this bit also indicates unsuccessful transmission (transmission stopped when lack of Carrier Sense has been detected).

Status Bit 9 — Transmission unsuccessful (stopped) due to Loss of $\overline{CTS}$.

Status Bit 8 — Transmission unsuccessful (stopped) due to DMA Underrun; i.e., the system did not supply data for transmission.

Status Bit 7 — Transmission Deferred, i.e., transmission was not immediate due to previous link activity.

Status Bit 6 — Heartbeat Indicator, Indicates that after a previously performed transmission, and before the most recently performed transmission, (Interframe Spacing) the CDT signal was monitored as active. This indicates that the Ethernet Transceiver Collision Detect logic is performing properly. The Heartbeat is monitored during the Interframe Spacing period.

Status Bit 5 — Transmission attempt was stopped because the number of collisions exceeded the maximum allowable number of retries.

MAX-COL (Bits 3–0) — The number of Collisions experienced during this frame. Max Col = 0 plus S5 = 1 indicates 16 collisions.

LINK OFFSET — As per standard Command Block (see the NOP Command for details)

TBD POINTER — In the 82586 and 32-bit Segmented modes this is the offset of the first Tx Buffer Descriptor containing the data to be transmitted. In the Linear mode this is the 32-bit address of the first Tx Buffer Descriptor on the list. If the TBD POINTER is all 1s it indicates that no TBD is used.

DEST ADDRESS — Contains the Destination Address of the frame. The least significant bit (MC) indicates the address type.

MC = 0: Individual Address.

MC = 1: Multicast or Broadcast Address.

If the Destination Address bits are all 1s this is a Broadcast Address.

LENGTH FIELD — The contents of this 2-byte field are user defined. In 802.3 it contains the length of the data field. It is placed in memory in the same order it is transmitted; i.e., most significant byte first, least significant byte second.

TCB COUNT — This 14-bit counter indicates the number of bytes that will be transmitted from the Transmit Command Block, starting from the third byte after the TCB COUNT field (address $n+12$ in the 32-bit Segmented mode, $N+16$ in the Linear mode). The TCB COUNT field can be any number of bytes (including an odd byte), this allows the user to transmit a frame with a header having an odd number of bytes. The TCB COUNT field is not used in the 82586 mode.

EOF Bit — Indicates that the whole frame is kept in the Transmit Command Block. In the Simplified memory model it must be always asserted.

The interpretation of what is transmitted depends on the No Source Address insertion configuration bit and the memory model being used.

NOTES

1. The Destination Address and the Length Field are sequential. The Length Field immediately follows the most significant byte of the Destination Address.
2. In case the 82596 is configured with No Source Address insertion bit equal to 0, the 82596 inserts its configured Source Address in the transmitted frame.
   - In the 82586 mode, or when the Simplified memory model is used, the Destination and Length fields of the transmitted frame are taken from the Transmit Command Block.
   - If the FLEXIBLE memory model is used, the Destination and Length fields of the transmitted frame can be found either in the TCB or TBD, depending on the TCB COUNT.
3. If the 82596 is configured with the Address/Length Field Location equal to 1, the 82596 does not insert its configured Source Address in the transmitted frame. The first (2 × Address Length) + 2 bytes of the transmitted frame are interpreted as Destination Address, Source Address, and Length fields respectively. The location of the first transmitted byte depends on the operational mode of the 82596:
   - In the 82586 mode, it is always the first byte of the first Tx Buffer.
   - In both the 32-bit Segmented and Linear modes it depends on the SF bit and TCB COUNT:
     - — In the Simplified memory mode the first transmitted byte is always the third byte after the TCB COUNT field.
     - — In the Flexible mode, if the TCB COUNT is greater than 0 then it is the third byte after the TCB COUNT field. If TCB COUNT equals 0 then it is first byte of the first Tx Buffer.
   - Transmit frames shorter than six bytes are invalid. The transmission will be aborted (only in 82586 mode) because of a DMA Underrun.
4. Frames which are aborted during transmission are jammed. Such an interruption of transmission can be caused by any reason indicated by any of the status bits 8, 9, 10 and 12.

Jamming Rules

1. Jamming will not start before completion of preamble transmission.
2. Collisions detected during transmission of the last 11 bits will not result in jamming.

The format of a Transmit Buffer Descriptor is:

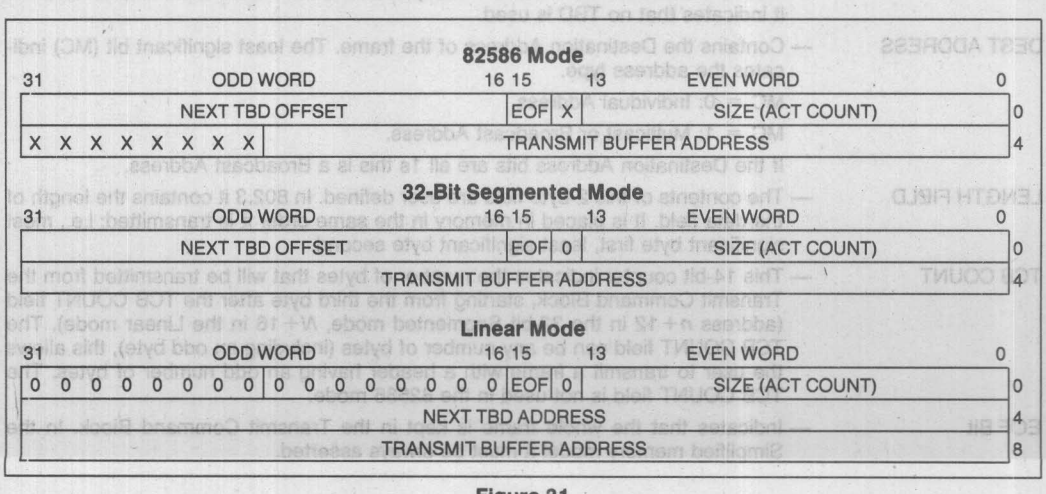


Figure 31

where:

EOF — This bit indicates that this TBD is the last one associated with the frame being transmitted. It is set by the CPU before transmit.

SIZE (ACT COUNT) — This 14-bit quantity specifies the number of bytes that hold information for the current buffer. It is set by the CPU before transmission.

NEXT TBD ADDRESS — In the 82586 and 32-bit Segmented modes, it is the offset of the next TBD on the list. In the Linear mode this is the 32-bit address of the next TBD on the list. It is meaningless if EOF = 1.

BUFFER ADDRESS — The starting address of the memory area that contains the data to be sent. In the 82586 mode, this is a 24-bit address (A31–A24 are considered to be zero). In the 32-bit Segmented and Linear modes this is a 32-bit address.

TDR

This operation activates Time Domain Reflectomet, which is a mechanism to detect open or short circuits on the link and their distance from the diagnosing station. The TDR command has no parameters. The TDR transmit sequence was changed, compared to the 82586, to form a regular transmission. The TDR bit stream is as follows.

— Preamble
— Source address
— Another Source address (the TDR frame is transmitted back to the sending station, so DEST ADR = SRC ADR).
— Data field containing 7Eh patterns.
— Jam Pattern, which is the inverse CRC of the transmitted frame.

Maximum length of the TDR frame is 2048 bits. If the 82596 senses collision while transmitting the TDR frame it transmits the jam pattern and stops the transmission. The 82596 then triggers an internal timer (STC); the timer is reset at the beginning of transmission and reset if CRS is returned. The timer measures the time elapsed from the start of transmission until an echo is returned. The echo is indicated by Collision Detect going active or a drop in the Carrier Sense signal. The following table lists the possible cases that the 82596 is able to analyze.

Conditions of TDR as Interpreted by the 82596

Transceiver Type / Condition	Ethernet	Non Ethernet
Carrier Sense was inactive for 2048-bit-time periods	Short or Open on the Transceiver Cable	NA
Carrier Sense signal dropped	Short on the Ethernet cable	NA
Collision Detect went active	Open on the Ethernet cable	Open on the Serial Link
The Carrier Sense Signal did not drop or the Collision Detect did not go active within 2048-bit time period	No Problem	No Problem

An Ethernet transceiver is defined as one that returns transmitted data on the receive pair and activates the Carrier Sense Signal while transmitting. A Non-Ethernet Transceiver is defined as one that does not do so.

The format of the Time Domain Reflectometer command is:

82586 and 32-Bit Segmented Modes

31 ODD WORD 16															15 EVEN WORD 0															
EL	S	I	X	X	X	X	X	X	X	X	X	X	1	0	1	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0
LNK OK	XVR PRB	ET OPN	ET SRT	X	TIME (11 bits)											A15	LINK OFFSET													A0

Linear Mode

31 ODD WORD 16															15 EVEN WORD 0															
EL	S	I	0	0	0	0	0	0	0	0	0	0	1	0	1	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0
A31	LINK ADDRESS																													A0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	LNK OK	XVR PRB	ET OPN	ET SRT	X	TIME (11 bits)								

Figure 32. TDR

where:

LINK ADDRESS, EL, B, C, I, S — As per standard Command Block (see the NOP command for details).

A — Indicates that the command was abnormally terminated due to CU Abort control command. If one, then the command was aborted, and if necessary it should be repeated. If this bit is zero, the command was not aborted.

Bits 19–28 — Reserved (0 in the 32-bit Segmented and Linear Modes).

CMD (Bits 16–18) — The TDR command. Value: 5h.

TIME — An 11-bit field that specifies the number of TxC cycles that elapsed before an echo was observed. No echo is indicated by a reception consisting of "1s" only. Because the network contains various elements such as transceiver links, transceivers, Ethernet, repeaters etc., the TIME is not exactly proportional to the problems distance.

LNK OK (Bit 15) — No link problem identified. TIME = 7FFh.

XCVR PRB (Bit 14) — Indicates a Transceiver problem. Carrier Sense was inactive for 2048-bit time period. LNK OK = 0. TIME = 7FFh.

ET OPN (Bit 13) — The transmission line is not properly terminated. Collision Detect went active and LNK OK = 0.

ET SRT (Bit 12) — There is a short circuit on the transmission line. Carrier Sense Signal dropped and LNK OK = 0.

DUMP

This command causes the contents of various 82596 registers to be placed in a memory area specified by the user. It is supplied as a 82596 self-diagnostic tool, and to provide registers of interest to the user. The format of the DUMP command is:

82586 and 32-Bit Segmented Modes

31															16	15															0
ODD WORD																EVEN WORD															
EL	S	I	X	X	X	X	X	X	X	X	X	X	1	1	0	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0	0
A15															A0	A15															A0
BUFFER OFFSET																LINK OFFSET															

Linear Mode

31															16	15															0
ODD WORD																EVEN WORD															
EL	S	I	X	X	X	X	X	X	X	X	X	X	1	1	0	C	B	OK	0	0	0	0	0	0	0	0	0	0	0	0	0
A31																															A0
LINK ADDRESS																															
A31																															A0
BUFFER ADDRESS																															

Figure 33. Dump

where:

LINK ADDRESS, EL, B, C, I, S — As per standard Command Block (see the NOP command for details).

OK — Indicates error free completion.

Bits 19–28 — Reserved (0 in the 32-bit Segmented and Linear Modes).

CMD (Bits 16–18) — The Dump command. Value: 6h.

BUFFER POINTER — In the 82586 and 32-bit Segmented modes this is the 16-bit-offset portion of the dump area address. In the Linear mode this is the 32-bit linear address of the dump area.

Dump Area Information Format

- The 82596 is not Dump compatible with the 82586 because of the 32-bit internal architecture. In 82586 mode the 82596 will dump the same number of bytes as the 82586. The compatible data will be marked with an asterisk.
- In 82586 mode the dump area is 170 bytes.
- The DUMP area format of the 32-bit Segmented and Linear modes is described in Figure 35.
- The size of the dump area of the 32-bit Segmented and Linear modes is 304 bytes.
- When the Dump is executed by the Port command an extra word will be appended to the Dump Area. The extra word is a copy of the Dump Area status word (containing the C, B, and OK Bits). The C and OK Bits are set when the 82596 has completed the Port Dump command.

7

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0	
DMA CONTROL REGISTER	00
CONFIGURE BYTES* 3, 2	02
CONFIGURE BYTES* 5, 4	04
CONFIGURE BYTES* 7, 6	06
CONFIGURE BYTES* 9, 8	08
CONFIGURE BYTES* 10	0A
I.A. BYTES 1, 0*	0C
I.A. BYTES 3, 2*	0E
I.A. BYTES 5, 4*	10
LAST T.X. STATUS*	12
T.X. CRC BYTES 1, 0*	14
T.X. CRC BYTES 3, 2*	16
R.X. CRC BYTES 1, 0*	18
R.X. CRC BYTES 3, 2*	1A
R.X. TEMP MEMORY 1, 0*	1C
R.X. TEMP MEMORY 3, 2*	1E
R.X. TEMP MEMORY 5, 4*	20
LAST RECEIVED STATUS*	22
HASH REGISTER BYTES 1, 0*	24
HASH REGISTER BYTES 3, 2*	26
HASH REGISTER BYTES 5, 4*	28
HASH REGISTER BYTES 7, 6*	2A
SLOT TIME COUNTER*	2C
WAIT TIME COUNTER*	2E
MICRO MACHINE**	30
REGISTER FILE	.
60 BYTES	6A
MICRO MACHINE LFSR**	6C
MICRO MACHINE**	6E
FLAG ARRAY	.
14 BYTES	7A
QUEUE MEMORY**	7C
CU PORT	.
8 BYTES	82
MICRO MACHINE ALU**	84
RESERVED**	86
M.M. TEMP A ROTATE R**	88
M.M. TEMP A**	8A
T.X. DMA BYTE COUNT**	8C
M.M. INPUT PORT ADDRESS**	8E
T.X. DMA ADDRESS	90
M.M. OUTPUT PORT**	92
R.X. DMA BYTE COUNT**	94
R.U. DMA ADDRESS**	96
M.M. OUTPUT PORT ADDRESS REGISTER**	98
RESERVED**	9A
BUS THROTTLE TIMERS	9C
DIU CONTROL REGISTER**	9E
RESERVED**	A0
DMA CONTROL REGISTER**	A2
BIU CONTROL REGISTER**	A4
M.M. DISPATCHER REG.**	A6
M.M. STATUS REGISTER**	A8

*The 82596 is not Dump compatible with the 82586 because of the 32-bit internal architecture. In 82586 mode the 82596 will dump the same number of bytes as the 82586.

**These bytes are not user defined, results may vary from Dump command to Dump command.

Figure 34. Dump Area Format—82586 Mode

31	0	
CONFIGURE BYTES 5, 4, 3, 2		00
CONFIGURE BYTES 9, 8, 7, 6		04
CONFIGURE BYTES 13, 12, 11, 10		08
I.A. BYTES 1, 0	X X X X X X X X	0C
I.A. BYTES 5, 2		10
TX CRC BYTES 0, 1	LAST T.X. STATUS	14
RX CRC BYTES 0, 1	TX CRC BYTES 3, 2	18
RX TEMP MEMORY 1, 0	RX CRC BYTES 3, 2	1C
R.X. TEMP MEMORY 5, 2		20
HASH REGISTERS 1, 0	LAST R.X. STATUS	24
HASH REGISTER BYTES 5, 2		28
SLOT TIME COUNTER	HASH REGISTERS 7, 6	2C
RECEIVE FRAME LENGTH	WAIT-TIME COUNTER	30
MICRO MACHINE**		34
REGISTER FILE 128 BYTES		. . B0
MICRO MACHINE LFSR**		B4
MICRO MACHINE**		B8
FLAG ARRAY 28 BYTES		. . D0
M.M. INPUT PORT** 16 BYTES		D4 . E0
MICRO MACHINE ALU**		E4
RESERVED**		E8
M.M. TEMP A ROTATE R.**		EC
M.M. TEMP A**		F0
T.X. DMA BYTE COUNT**		F4
M.M. INPUT PORT ADDRESS REGISTER**		F8
T.X. DMA ADDRESS**		FC
M.M. OUTPUT PORT REGISTER**		100
R.X. DMA BYTE COUNT**		104
M.M. OUTPUT PORT ADDRESS REGISTER**		108
R.X. DMA ADDRESS REGISTER**		10C
RESERVED**		110
BUS THROTTLE TIMERS		114
DIU CONTROL REGISTER**		118
RESERVED**		11C
DMA CONTROL REGISTER**		120
BIU CONTROL REGISTER**		124
M.M. DISPATCHER REG.**		128
M.M. STATUS REGISTER**		12C

*The 82596 is not Dump compatible with the 82586 because of the 32-bit internal architecture. In 82586 mode the 82596 will dump the same number of bytes as the 82586.
**These bytes are not user defined, results may vary from Dump command to Dump command.

Figure 35. Dump Area Format—Linear and 32-Bit Segmented Mode

7

Diagnose

The Diagnose Command triggers an internal self-test procedure that checks internal 82596 hardware, which includes:

- Exponential Backoff Random Number Generator (Linear Feedback Shift Register).
- Exponential Backoff Timeout Counter.
- Slot Time Period Counter.
- Collision Number Counter.
- Exponential Backoff Shift Register.
- Exponential Backoff Mask Logic.
- Timer Trigger Logic.

This procedure checks the operation of the Backoff block, which resides in the serial side and is not easily controlled. The Diagnose command is performed in two phases.

The format of the 82596 Diagnose command is:

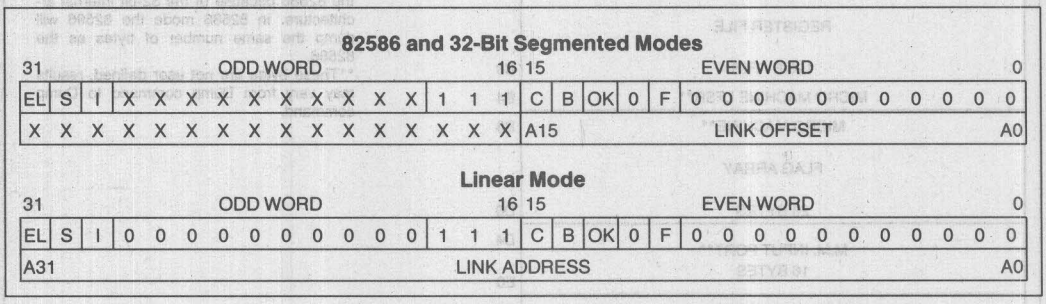


Figure 36. Diagnose

where:

LINK ADDRESS, EL, B, C, I, S	— As per standard Command Block (see the NOP command for details).
Bits 19–28	— Reserved (0 in the 32-bit Segmented and Linear Modes).
CMD (bits 16–18)	— The Diagnose command. Value: 7h.
OK (bit 13)	— Indicates error free completion.
F (bit 11)	— Indicates that the self-test procedure has failed.

RECEIVE FRAME DESCRIPTOR

Each received frame is described by one Receive Frame Descriptor (see Figure 37). Two new memory structures are available for the received frames. The structures are available only in the Linear and 32-bit Segmented modes.

Simplified Memory Structure

The first is the Simplified memory structure, the data section of the received frame is part of the RFD and is located immediately after the Length Field. Receive Buffer Descriptors are not used with the Simplified structure, it is primarily used to make programming easier. If the length of the data area described in the Size Field is smaller than the incoming frame, the following happens.

1. The received frame is truncated.
2. The No Resource error counter is updated.
3. If the 82596 is configured to Save Bad Frames the RFD is not reused; otherwise, the same RFD is used to hold the next received frame, and the only action taken regarding the truncated frame is to update the counter.
4. The 82596 continues to receive the next frame in the next RFD.

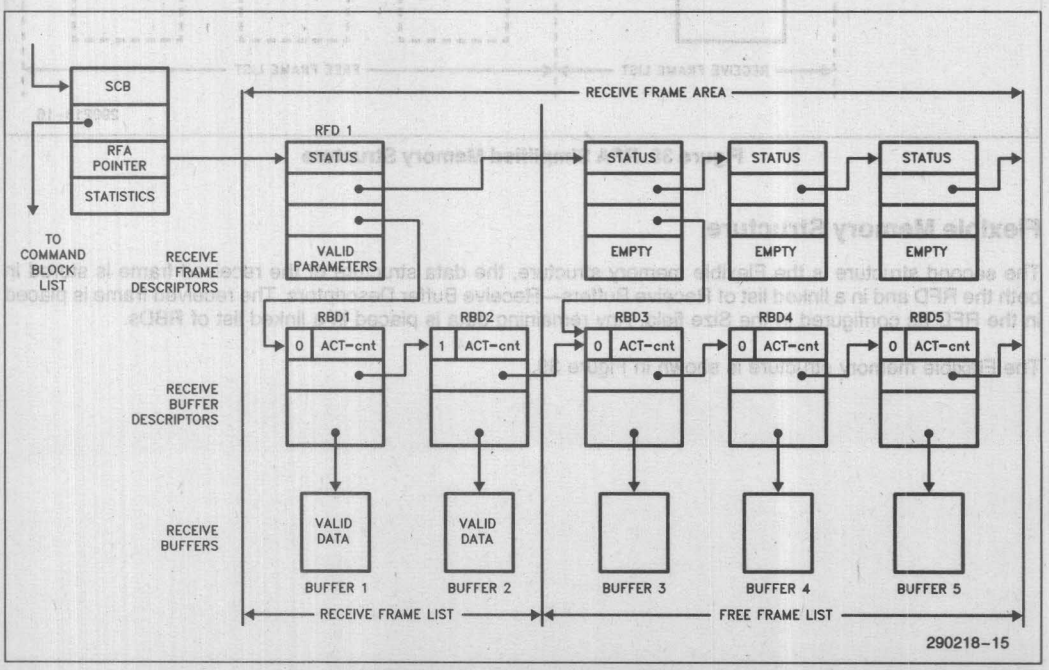


Figure 37. The Receive Frame Area

Note that this sequence is very useful for monitoring. If the 82596 is configured to Save Bad Frames, to receive in Promiscuous mode, and to use the Simplified memory structure, any programmed length of received data can be saved in memory.

The Simplified memory structure is shown in Figure 38.

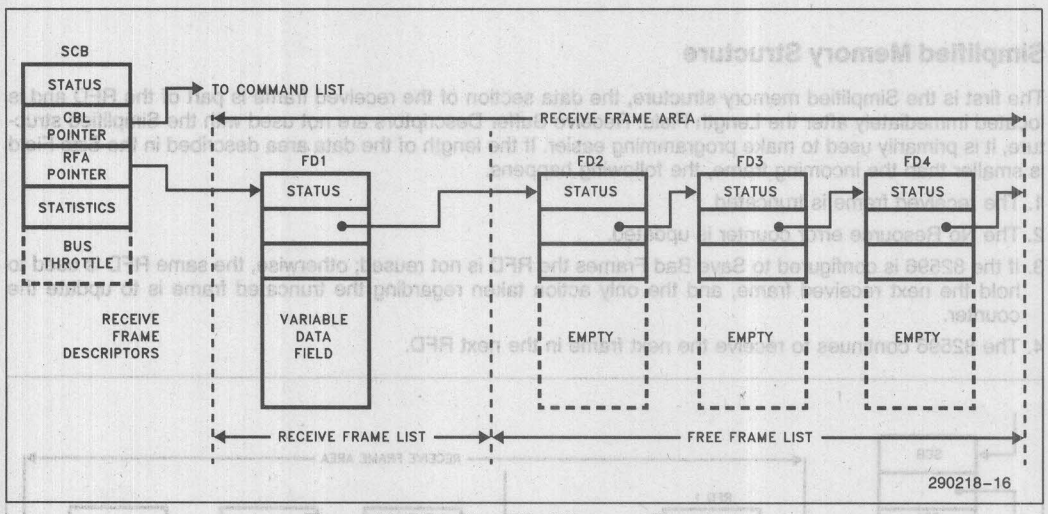


Figure 38. RFA Simplified Memory Structure

Flexible Memory Structure

The second structure is the Flexible memory structure, the data structure of the received frame is stored in both the RFD and in a linked list of Receive Buffers—Receive Buffer Descriptors. The received frame is placed in the RFD as configured in the Size field. Any remaining data is placed in a linked list of RBDs.

The Flexible memory structure is shown in Figure 39.

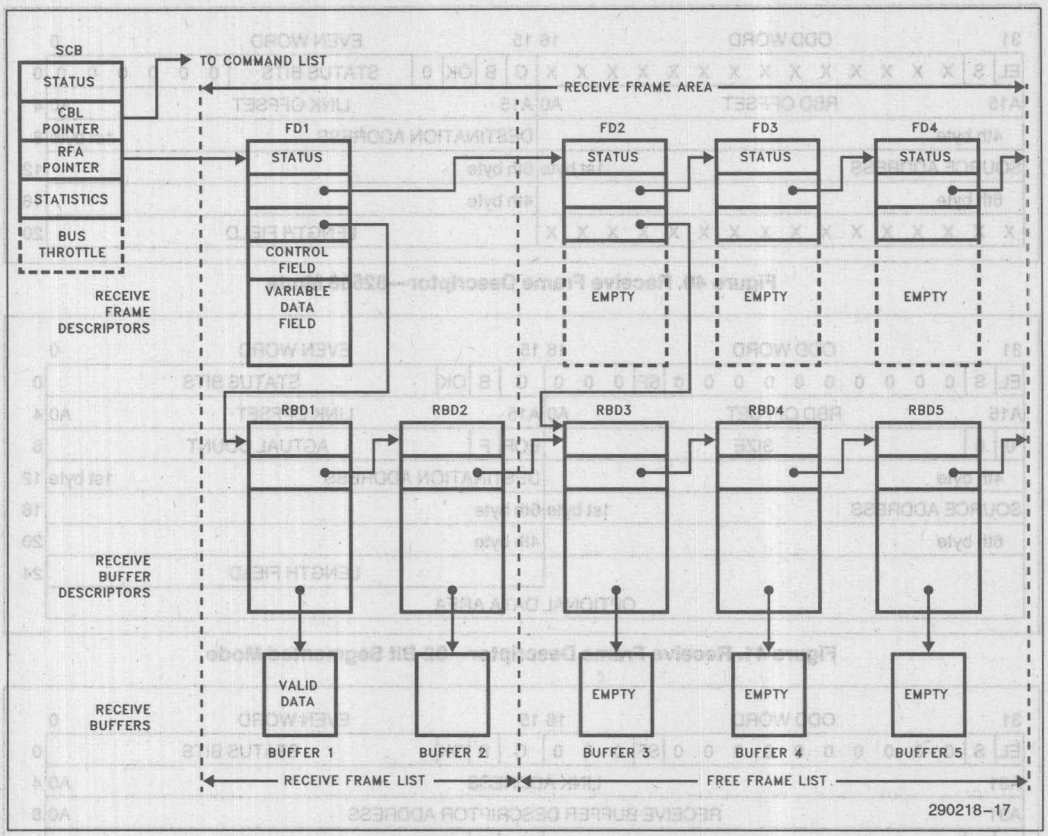


Figure 39. RFA Flexible Memory Structure

Buffers on the receive side can be different lengths. The 82596 will not place more bytes into a buffer than indicated in the associated RBD. The 82596 will fetch the next RBD before it is needed. The 82596 will attempt to receive frames as long as the FBL is not exhausted. If there are no more buffers, the 82596 Receive Unit will enter the No Resources state. Before starting the RU, the CPU must place the FBL pointer in the RBD pointer field of the first RFD. All remaining RBD pointer fields for subsequent RFDs should be "1s." If the Receive Frame Descriptor and the associated Receive Buffers are not reused (e.g., the frame is properly received or the 82596 is configured to Save Bad Frames), the 82596 writes the address of the next free RBD to the RBD pointer field of the next RFD.

7

Receive Buffer Descriptor (RBD)

The RBDs are used to store received data in a flexible set of linked buffers. The portion of the frame's data field that is outside the RFD is placed in a set of buffers chained by a sequence of RBDs. The RFD points to the first RBD, and the last RBD is flagged with an EOF bit set to 1. Each buffer in the linked list of buffers related to a particular frame can be any size up to 2^{14} bytes but must be word aligned (begin on an even numbered byte). This ensures optimum use of the memory resources while maintaining low overhead. All buffers in a frame are filled with the received data except for the last, in which the actual count can be smaller than the allocated buffer space.

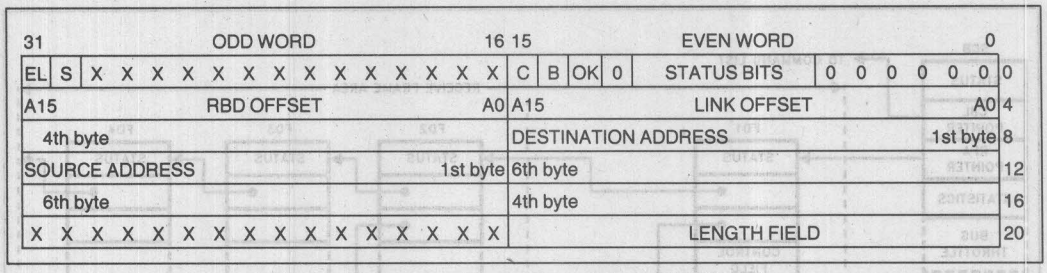


Figure 40. Receive Frame Descriptor—82586 Mode

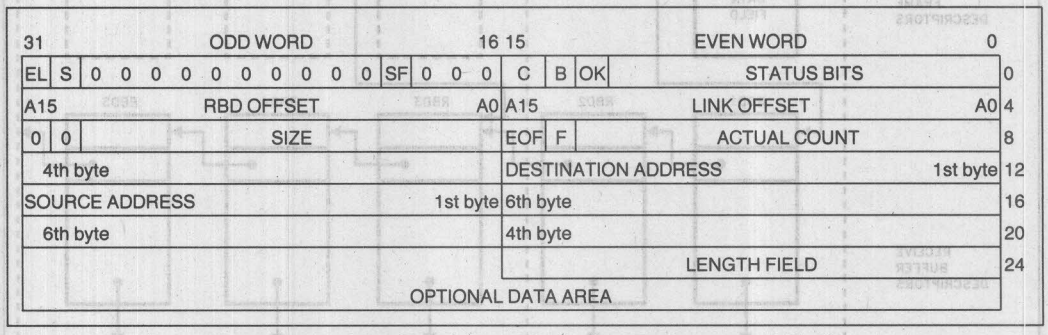


Figure 41. Receive Frame Descriptor—32-Bit Segmented Mode

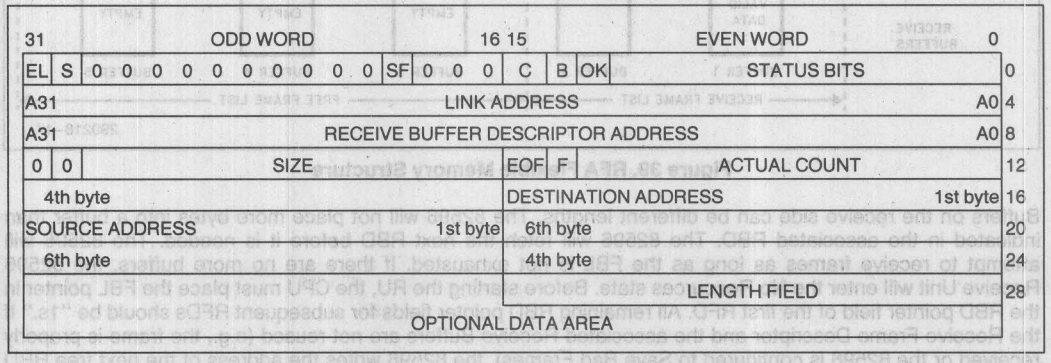


Figure 42. Receive Frame Descriptor—Linear Mode

where:

EL — When set, this bit indicates that this RFD is the last one on the RDL.

S — When set, this bit suspends the RU after receiving the frame.

SF — This bit selects between the Simplified or the Flexible mode.

0 — Simplified mode, all the RX data is in the RFD. RBD ADDRESS field is all "1s."

1 — Flexible mode. Data is in the RFD and in a linked list of Receive Buffer Descriptors.

C — This bit indicates the completion of frame reception. It is set by the 82596.

B — This bit indicates that the 82596 is currently receiving this frame, or that the 82596 is ready to receive the frame. It is initially set to 0 by the CPU. The 82596 sets it to 1 when reception set up begins, and to 0 upon completion. The C and B bits are set during the same operation.

OK (bit 13) — Frame received successfully, without errors. RFDs with bit 13 equal to 0 are possible only if the save bad frames, configuration option is selected. Otherwise all frames with errors will be discarded, although statistics will be collected on them.

STATUS — The results of the Receive operation. Defined bits are,

- Bit 12: Length error if configured to check length
- Bit 11: CRC error in an aligned frame
- Bit 10: Alignment error (CRC error in misaligned frame)
- Bit 9: Ran out of buffer space—no resources
- Bit 8: DMA Overrun failure to acquire the system bus.
- Bit 7: Frame too short.
- Bit 6: No EOP flag (for Bit stuffing only)
- Bit 5: When the SF bit equals zero, and the 82596 is configured to save bad frames, this bit signals that the receive frame was truncated. Otherwise it is zero.
- Bits 2–4: Zeros
- Bit 1: When it is zero, the destination address of the received frame matches the IA address. When it is a 1, the destination address of the received frame did not match the individual address. For example, a multicast address or broadcast address will set this bit to a 1.
- Bit 0: Receive collision, a collision is detected during reception.

LINK ADDRESS — A 16-bit offset (32-bit address in the Linear mode) to the next Receive Frame Descriptor. The Link Address of the last frame can be used to form a cyclical list.

RBD POINTER — The offset (address in the Linear mode) of the first RBD containing the received frame data. An RBD pointer of all ones indicates no RBD.

EOF
F
SIZE
ACT COUNT — These fields are for the Simplified and Flexible memory models. They are exactly the same as the respective fields in the Receive Buffer Descriptor. See the next section for detailed explanation of their functions.

MC — Multicast bit.

DESTINATION ADDRESS — The contents of the destination address of the receive frame. The field is 0 to 6 bytes long.

SOURCE ADDRESS — The contents of the Source Address field of the received frame. It is 0 to 6 bytes long.

LENGTH FIELD — The contents of this 2-byte field are user defined. In 802.3 it contains the length of the data field. It is placed in memory in the same order it is received, i.e., most significant byte first, least significant byte second.

7

NOTES

1. The Destination address, Source address and Length fields are packed, i.e., one field immediately follows the next.
2. The affect of Address/Length Location (No Source Address Insertion) configuration parameter while receiving is as follows:

— 82586 Mode: The Destination address, Source address and Length field are not used, they are placed in the RX data buffers.

— 32-Bit Segmented and Linear Modes: when the Simplified memory model is used, the Destination address, Source address and Length fields reside in their respective fields in the RFD. When the Flexible memory strucrture is used the Destination address, Source address, and Length field locations depend on the SIZE field of the RFD. They can be placed in the RFD, in the RX data buffers, or partially in the RFD and the rest in the RX data buffers, depending on the SIZE field value.

82586 Mode

31 ODD WORD 16	15 EVEN WORD 0	
A15 NEXT RBD OFFSET	A0 EOF F ACTUAL COUNT	0
X X X X X X X X A23	RECEIVE BUFFER ADDRESS A0	4
X X X X X X X X X X X X X X X X	EL X SIZE	8

32-Bit Segmented Mode

31 ODD WORD 16	15 EVEN WORD 0	
A15 NEXT RBD OFFSET	A0 EOF F ACTUAL COUNT	0
A31 RECEIVE BUFFER ADDRESS	A0	4
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	EL P SIZE	8

Linear Mode

31 ODD WORD 16	15 EVEN WORD 0	
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	EOF F ACTUAL COUNT	0
A31 NEXT RBD ADDRESS	A0	4
A31 RECEIVE BUFFER ADDRESS	A0	8
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	EL P SIZE	

Figure 43. Receive Buffer Descriptor

where:

EOF — Indicates that this is the last buffer related to the frame. It is cleared by the CPU before starting the RU, and is written by the 82596 at the end of reception of the frame.

F — Indicates that this buffer has already been used. The Actual Count has no meaning unless the F bit equals one. This bit is cleared by the CPU before starting the RU, and is set by the 82596 after the associated buffer has been. This bit has the same meaning as the Complete bit in the RFD and CB.

ACT COUNT — This 14-bit quantity indicates the number of meaningful bytes in the buffer. It is cleared by the CPU before starting the RU, and is written by the 82596 after the associated buffer has already been used. In general, after the buffer is full, the Actual Count value equals the size field of the same buffer. For the last buffer of the frame, Actual Count can be less than the buffer size.

NEXT BD ADDRESS — The offset (absolute address in the Linear mode) of the next RBD on the list. It is meaningless if EL = 1.

BUFFER ADDRESS — The starting address of the memory area that contains the received data. In the 82586 mode, this is a 24-bit address (with pins A24–A31 = 0). In the 32-bit Segmented and Linear modes this is a 32-bit address.

EL — Indicates that the buffer associated with this RBD is last in the FBL.

P — This bit indicates that the 82596 has already prefetched the RBDs and any change in the RBD data will be ignored. This bit is valid only in the new 82596 memory modes, and if this feature has been enabled during configure command. The 82596 Prefetches the RBDs in locked cycles; after prefetching the RBD the 82596 performs a write cycle where the P bit is set to one and the rest of the data remains unchanged. The CPU is responsible for resetting it in all RBDs. The 82596 will not check this bit before setting it.

SIZE — This 14-bit quantity indicates the size, in bytes, of the associated buffer. This quantity must be an even number.

7

ELECTRICAL AND TIMING CHARACTERISTICS

DC Characteristics

T_C = 0°C–85°C, V_{CC} = 5V ±10% LE/$\overline{BE}$ have MOS levels (see V_{MIL}, V_{MIH}).
All other signals have TTL levels (see V_{IL}, V_{IH}, V_{OL}, V_{OH}).

Symbol	Parameter	Min	Max	Units	Notes
V_{IL}	Input Low Voltage (TTL)	−0.3	+0.8	V	
V_{IH}	Input High Voltage (TTL)	2.0	V_{CC} + 0.3	V	
V_{MIL}	Input Low Voltage (MOS)	−0.3	+0.8	V	
V_{MIH}	Input High Voltage (MOS)	3.7	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage (TTL)		0.45	V	I_{OL} = 4.0 mA(1)
V_{CIL}	$\overline{RXC}$, $\overline{TXC}$ Input Low Voltage	−0.5	0.6	V	
V_{CIH}	$\overline{RXC}$, $\overline{TXC}$ Input High Voltage	3.3	V_{CC}+0.5	V	
V_{OH}	Output High Voltage (TTL)	2.4		V	I_{OH} = 0.9mA–1 mA(1)
I_{LI}	Input Leakage Current		±15	μA	0 ≤ V_{IN} ≤ V_{CC}
I_{LO}	Output Leakage Current		±15	μA	0.45 < V_{OUT} < V_{CC}
C_{IN}	Capacitance of Input Buffer		10	pF	FC = 1 MHz
C_{OUT}	Capacitance of Input/Output Buffer		12	pF	FC = 1 MHz
C_{CLK}	CLK Capacitance		20	pF	FC = 1 MHz
I_{CC}	Power Supply		200	mA	At 25 MHz
I_{CC}	Power Supply		300	mA	At 33 MHz

PRELIMINARY DATASHEET SUPPLEMENT SEE INTEL FOR

AC Characteristics

82596CA INPUT/OUTPUT SYSTEM TIMINGS

T_C = 0°C–85°C, V_{CC} = 5V ±10%. These timing assume the C_L on all outputs is 50 pF unless otherwise specified. C_L can be 20 pF to 120 pF however timings must be derated. All timing requirements are given in nanoseconds.

Symbol	Parameter	25 MHz		Notes
		Min	Max	
	Operating Frequency	12.5 MHz	25 MHz	1X CLK Input
T1	CLK Period	40	80	
T1a	CLK Period Stability		0.1%	Adjacent CLK Δ
T2	CLK High	14		2.0V
T3	CLK Low	14		0.8V
T4	CLK Rise Time		4	0.8V to 2.0V
T5	CLK Fall Time		4	2.0V to 0.8V
T6	$\overline{BEn}$, $\overline{LOCK}$, and A2–A31 Valid Delay	3	22	
T6a	$\overline{BLAST}$, $\overline{PCHK}$ Valid Delay	3	27	
T7	$\overline{BEn}$, $\overline{LOCK}$, $\overline{BLAST}$, A2–A31 Float Delay	3	30	
T8	W/$\overline{R}$ and $\overline{ADS}$ Valid Delay	3	22	
T9	W/$\overline{R}$ and $\overline{ADS}$ Float Delay	3	30	
T10	D0–D31, DPn Write Data Valid Delay	3	22	
T11	D0–D31, DPn Write Data Float Delay	3	30	
T12	HOLD Valid Delay	3	22	
T13	CA and BREQ Setup Time	7		1, 2
T14	CA and BREQ Hold Time	3		1, 2
T15	$\overline{BS16}$ Setup Time	8		2
T16	$\overline{BS16}$ Hold Time	3		2
T17	$\overline{BRDY}$, $\overline{RDY}$ Setup Time	8		2
T18	$\overline{BRDY}$, $\overline{RDY}$ Hold Time	3		2
T19	D0–D31, DPn READ Setup Time	5		2
T20	D0–D31, DPn READ Hold Time	3		2
T21	AHOLD and HLDA Setup Time	10		1, 2
T22	AHOLD Hold Time	3		1, 2
T22a	HLDA Hold Time	3		1, 2
T23	RESET Setup Time	10		1, 2
T24	RESET Hold Time	3		1, 2
T25	INT/$\overline{INT}$ Valid Delay	1	26	
T26	CA and BREQ, $\overline{PORT}$ Pulse Width	2 T1		1, 2, 3
T27	D0–D31 CPU $\overline{PORT}$ Access Setup Time	5		2
T28	D0–D31 CPU $\overline{PORT}$ Access Hold Time	3		2
T29	$\overline{PORT}$ Setup Time	7		2
T30	$\overline{PORT}$ Hold Time	3		2
T31	$\overline{BOFF}$ Setup Time	10		2
T32	$\overline{BOFF}$ Hold Time	3		2

PRELIMINARY DATASHEET SEE INTEL FOR DATA SUPPLEMENT

AC Characteristics (Continued)

82596CA INPUT/OUTPUT SYSTEM TIMINGS

T_C = 0°C–85°C, V_{CC} = 5V ±5%. These timing assume the C_L on all outputs is 50 pF unless otherwise specified. C_L can be 20 pF to 120 pF, however timings must be derated. All timing requirements are given in nanoseconds.

Symbol	Parameter	33 MHz		Notes
		Min	Max	
	Operating Frequency	12.5 MHz	33 MHz	1X CLK Input
T1	CLK Period	30	80	
T1a	CLK Period Stability		0.1%	Adjacent CLK Δ
T2	CLK High	11		2.0V
T3	CLK Low	11		0.8V
T4	CLK Rise Time		3	0.8V to 2.0V
T5	CLK Fall Time		3	2.0V to 0.8V
T6	$\overline{BE}$n, $\overline{LOCK}$, and A2–A31 Valid Delay	3	19	
T6a	$\overline{BLAST}$, $\overline{PCHK}$ Valid Delay	3	22	
T7	$\overline{BE}$n, $\overline{LOCK}$, $\overline{BLAST}$, A2–A31 Float Delay	3	20	
T8	W/$\overline{R}$ and $\overline{ADS}$ Valid Delay	3	19	
T9	W/$\overline{R}$ and $\overline{ADS}$ Float Delay	3	20	
T10	D0–D31, DPn Write Data Valid Delay	3	19	
T11	D0–D31, DPn Write Data Float Delay	3	20	
T12	HOLD Valid Delay	3	19	
T13	CA and $\overline{BREQ}$ Setup Time	7		1, 2
T14	CA and $\overline{BREQ}$ Hold Time	3		1, 2
T15	$\overline{BS16}$ Setup Time	6		2
T16	$\overline{BS16}$ Hold Time	3		2
T17	$\overline{BRDY}$, $\overline{RDY}$ Setup Time	6		2
T18	$\overline{BRDY}$, $\overline{RDY}$ Hold Time	3		2
T19	D0–D31, DPn READ Setup Time	5		2
T20	D0–D31, DPn READ Hold Time	3		2
T21	AHOLD and HLDA Setup Time	8		1, 2
T22	AHOLD Hold Time	3		1, 2

SEE INTEL PRELIMINARY DATASHEET FOR SUPPLEMENT

AC Characteristics (Continued)

82596CA INPUT/OUTPUT SYSTEM TIMINGS

C_L on all outputs is 50 pF unless otherwise specified.
All timing requirements are given in nanoseconds.

Symbol	Parameter	33 MHz		Notes
		Min	Max	
T22a	HLDA Hold Time	3		1, 2
T23	RESET Setup Time	8		1, 2
T24	RESET Hold Time	3		1, 2
T25	INT/$\overline{\text{INT}}$ Valid Delay	1	20	
T26	CA and BREQ, $\overline{\text{PORT}}$ Pulse Width	2T1		1, 2, 3
T27	D0–D31 CPU $\overline{\text{PORT}}$ Access Setup Time	5		2
T28	D0–D31 CPU $\overline{\text{PORT}}$ Access Hold Time	3		2
T29	$\overline{\text{PORT}}$ Setup Time	7		2
T30	$\overline{\text{PORT}}$ Hold Time	3		2
T31	$\overline{\text{BOFF}}$ Setup Time	8		2
T32	$\overline{\text{BOFF}}$ Hold Time	3		2

NOTES:
1. RESET, HLDA, and CA are internally synchronized. This timing is to guarantee recognition at next clock for RESET, HLDA and CA.
2. All set-up, hold and delay timings are at maximum frequency specification Fmax, and must be derated according to the following equation for operation at lower frequencies:
   Tderated = (Fmax/Fopr) × T
   where:
   Tderate = Specifies the value to derate the specification.
   Fmax = Maximum operating frequency.
   Fopr = Actual operating frequency.
   T = Specification at maximum frequency.
   This calculation only provides a rough estimate for derating the frequency. For more detailed information, contact your Intel Sales Office for the data sheet supplement.
3. CA pulse width need only be 1 T1 wide if the set up and hold times are met; BREQ must meet setup and hold times and need only be 1 T1 wide.

TRANSMIT/RECEIVE CLOCK PARAMETERS

Symbol	Parameter	20 MHz		Notes
		Min	Max	
T36	$\overline{\text{TxC}}$ Cycle	50		1, 3
T38	$\overline{\text{TxC}}$ Rise Time		5	1
T39	$\overline{\text{TxC}}$ Fall Time		5	1
T40	$\overline{\text{TxC}}$ High Time	19		1, 3
T41	$\overline{\text{TxC}}$ Low Time	18		1, 3
T42	TxD Rise Time		10	4
T43	TxD Fall Time		10	4
T44	TxD Transition	20		2, 4
T45	$\overline{\text{TxC}}$ Low to TxD Valid		25	4, 6
T46	$\overline{\text{TxC}}$ Low to TxD Transition		25	2, 4
T47	$\overline{\text{TxC}}$ High to TxD Transition		25	2, 4
T48	$\overline{\text{TxC}}$ Low to TxD High (At End of Transition)		25	4

PRELIMINARY SEE INTEL FOR DATASHEET SUPPLEMENT

TRANSMIT/RECEIVE CLOCK PARAMETERS (Continued)

Symbol	Parameter	20 MHz		Notes
		Min	Max	
$\overline{RTS}$ AND $\overline{CTS}$ PARAMETERS				
T49	$\overline{TxC}$ Low to $\overline{RTS}$ Low, Time to Activate $\overline{RTS}$		25	5
T50	$\overline{CTS}$ Low to $\overline{TxC}$ Low, $\overline{CTS}$ Setup Time		20	
T51	$\overline{TxC}$ Low to $\overline{CTS}$ Invalid, $\overline{CTS}$ Hold Time	10		7
T52	$\overline{TxC}$ Low to $\overline{RTS}$ High		25	5
RECEIVE CLOCK PARAMETERS				
T53	$\overline{RXC}$ Cycle	50		1, 3
T54	$\overline{RXC}$ Rise Time		5	1
T55	$\overline{RXC}$ Fall Time		5	1
T56	$\overline{RXC}$ High Time	19		1
T57	$\overline{RXC}$ Low Time	18		1
RECEIVED DATA PARAMETERS				
T58	RXD Setup Time	20		6
T59	RXD Hold Time	10		6
T60	RXD Rise Time		10	
T61	RXD Fall Time		10	
$\overline{CRS}$ AND $\overline{CDT}$ PARAMETERS				
T62	$\overline{CDT}$ Low to $\overline{TXC}$ HIGH External Collision Detect Setup Time	20		
T63	$\overline{TXC}$ High to $\overline{CDT}$ Inactive, $\overline{CDT}$ Hold Time	10		
T64	$\overline{CDT}$ Low to Jam Start			10
T65	$\overline{CRS}$ Low to $\overline{TXC}$ High, Carrier Sense Setup Time	20		
T66	$\overline{TXC}$ High to $\overline{CRS}$ Inactive, $\overline{CRS}$ Hold Time (Internal Collision Detect)	10		
T67	$\overline{CRS}$ High to Jamming Start,			12
T68	Jamming Period			11
T69	$\overline{CRS}$ High to $\overline{RXC}$ High, $\overline{CRS}$ Inactive Setup Time	30		
T70	$\overline{RXC}$ High to $\overline{CRS}$ High, $\overline{CRS}$ Inactive Hold Time	10		

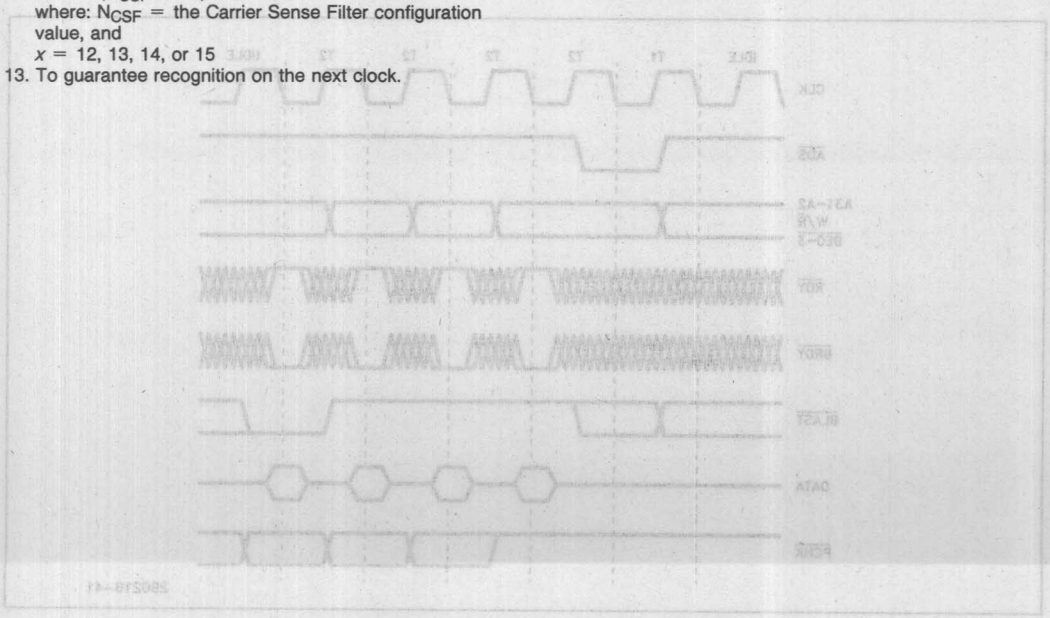
PRELIMINARY
SEE INTEL FOR DATASHEET
SUPPLEMENT

TRANSMIT/RECEIVE CLOCK PARAMETERS (Continued)

Symbol	Parameter	20 MHz		Notes
		Min	Max	
INTERFRAME SPACING PARAMETERS				
T71	Interframe Delay			9
EXTERNAL LOOPBACK-PIN PARAMETERS				
T72	$\overline{TXC}$ Low to $\overline{LPBK}$ Low		T36	4
T73	$\overline{TXC}$ Low to $\overline{LPBK}$ High		T36	4

PRELIMINARY DATASHEET SUPPLEMENT SEE INTEL FOR

NOTES:
1. Special MOS levels. V_{CIL} = 0.9V and V_{CIH} = 3.0V.
2. Manchester only.
3. Manchester. Needs 50% duty cycle.
4. 1 TTL load + 50 pF.
5. 1 TTL load + 100 pF.
6. NRZ only.
7. Abnormal end of transmission—CTS expires before RTS.
8. Normal end to transmission.
9. Programmable value:
   T71 = N_{IFS} • T36
   where: N_{IFS} = the IFS configuration value
   (if N_{IFS} is less than 12 then N_{IFS} is forced to 12).
10. Programmable value:
    T64 = (N_{CDF} • T36) + x • T36
    (If the collision occurs after the preamble)
    where:
    N_{CDF} = the collision detect filter configuration value,
    and
    x = 12, 13, 14, or 15
11. T68 = 32 • T36
12. Programmable value:
    T67 = (N_{CSF} • T36) + x • T36
    where: N_{CSF} = the Carrier Sense Filter configuration value, and
    x = 12, 13, 14, or 15
13. To guarantee recognition on the next clock.



7

82596CA BUS OPERATION

The following figures show the 82596CA basic bus cycle and basic burst cycle.

Please refer to the *32-Bit LAN Components Manual.*

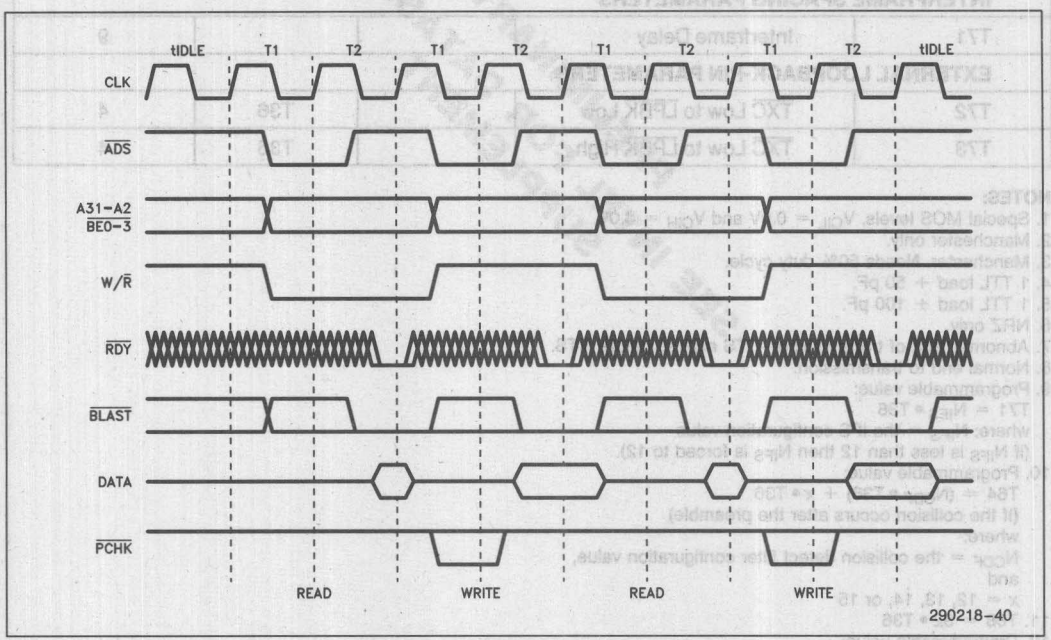


Figure 44. Basic 82596CA Bus Cycle

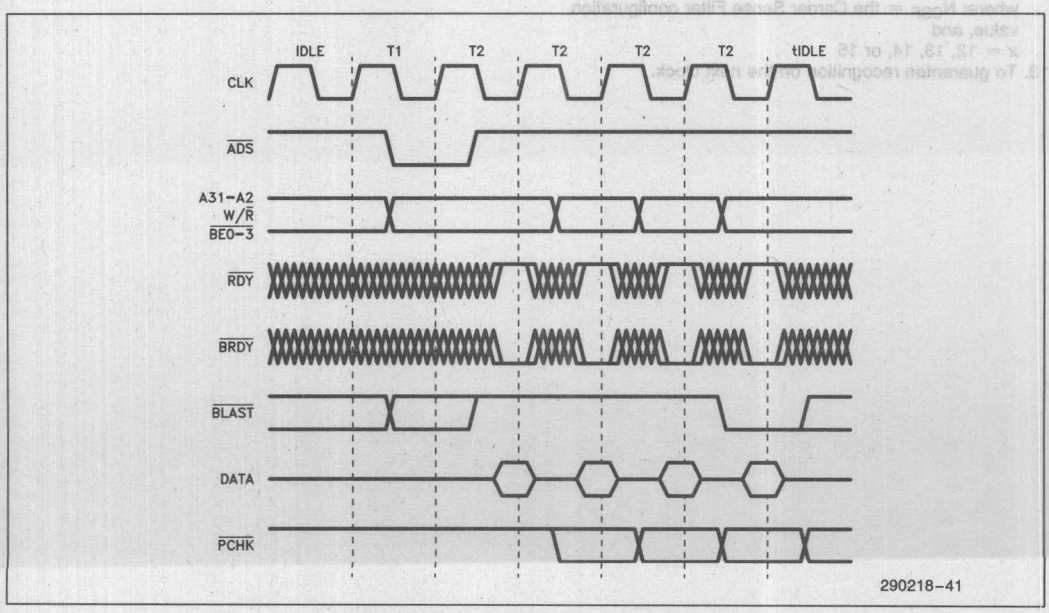


Figure 45. Basic 82596CA Burst Cycle

SYSTEM INTERFACE A.C. TIMING CHARACTERISTICS

The measurements should be done at:

- T_C = 0°C–85°C, V_{CC} = 5V ±10%, C = 50 pF unless otherwise specified.
- A.C. testing inputs are driven at 2.4V for a logic "1" and 0.45V for a logic "0".
- Timing measurements are made at 1.5V for both logic "1" and "0".
- Rise and Fall time of inputs and outputs signals are measured between 0.8V and 2.0V respectively unless otherwise specified.
- All timings are relative to CLK crossing the 1.5V level.
- All A.C. parameters are valid only after 100 μs from power up.

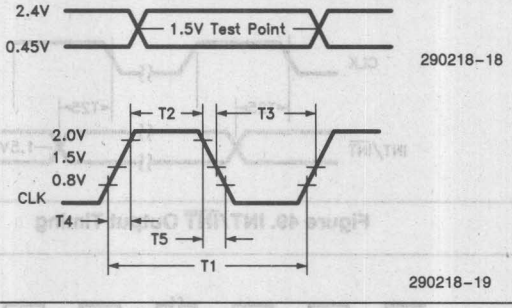
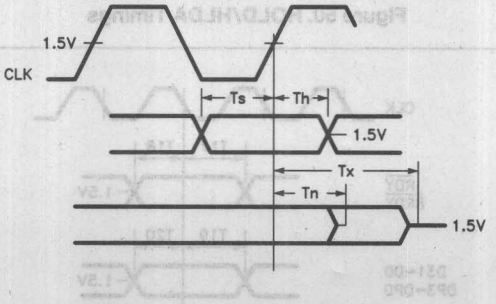


Figure 46. CLK Timings

Two types of timing specifications are presented below:

1. Input Timing—minimum setup and hold times.
2. Output Timings—output delays and float times from CLK rising edge.

Figure 47 defines how the measurements should be done:



LEGEND:
Ts = Input Setup Time
Th = Input Hold Time
Tn = Minimum output delay or Mininum float delay
Tx = Maximum output delay or Maximum float delay

Figure 47. Drive Levels and Measurements Points for A.C. Specifications

Ts = T13, T15, T17, T19, T21, T23, T27, T29, T31
Th = T14, T16, T18, T20, T22, T22a, T24, T28, T30, T32
Tn = T6, T6a, T7, T8, T9, T10, T11, T12, T25
Tx = T6, T6a, T7, T8, T9, T10, T11, T12, T25

INPUT WAVEFORMS

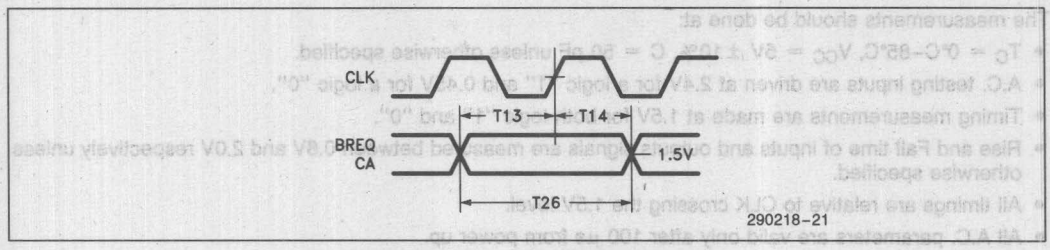


Figure 48. CA and BREQ Input Timing

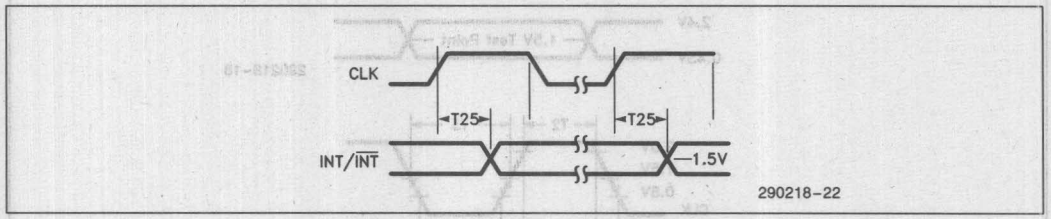


Figure 49. INT/INT Output Timing

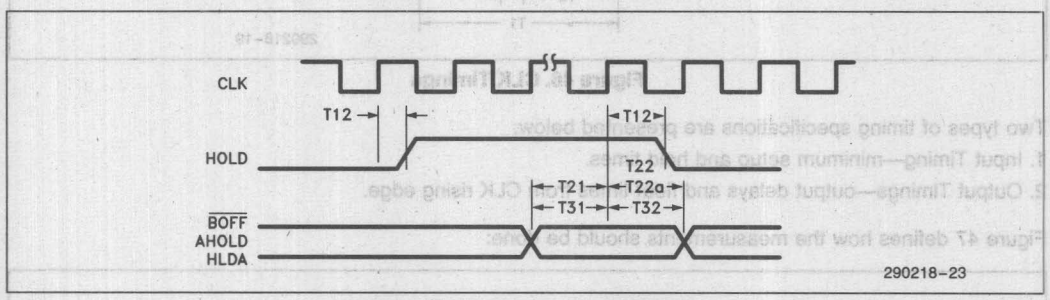


Figure 50. HOLD/HLDA Timings

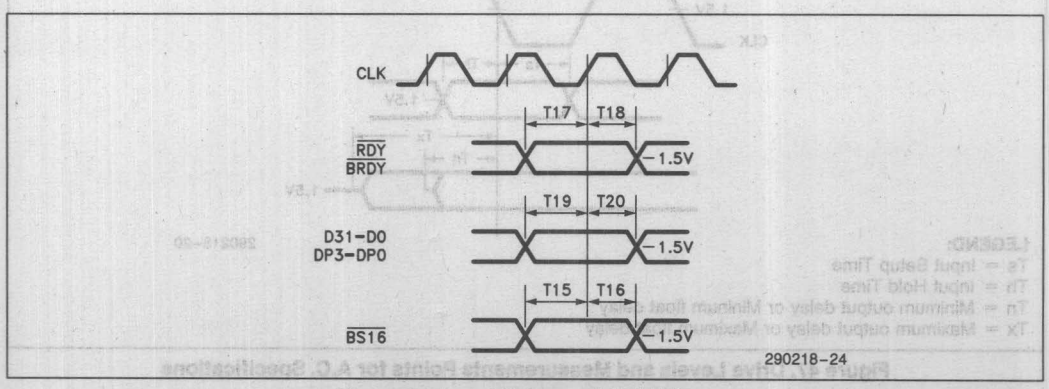


Figure 51. Input Setup and Hold Time

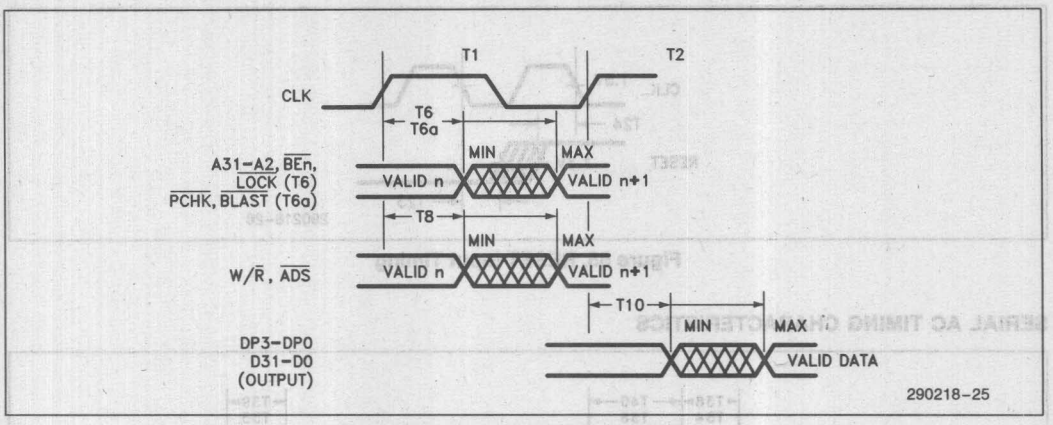


Figure 52. Output Valid Delay Timing

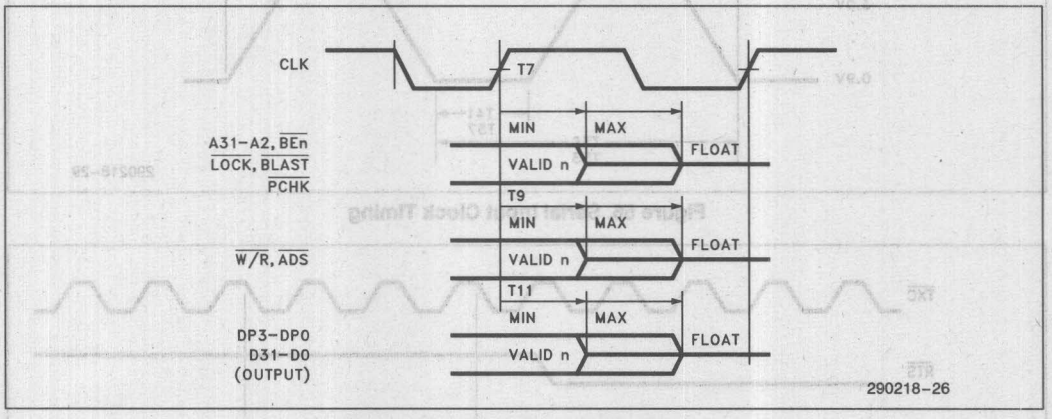


Figure 53. Output Float Delay Timing

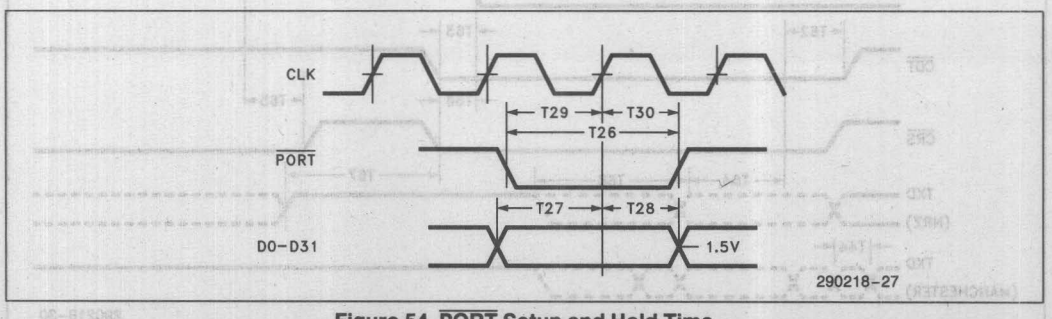


Figure 54. PORT Setup and Hold Time

7

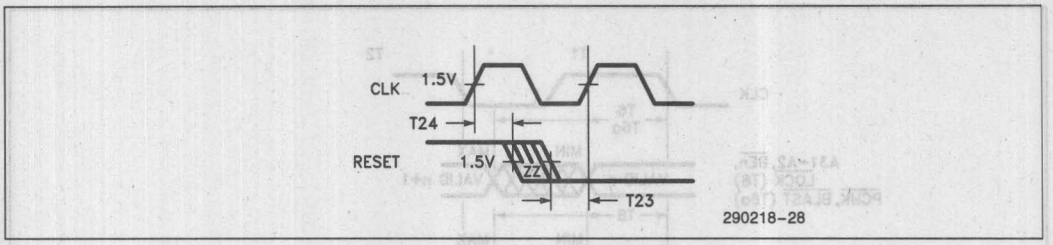


Figure 55. RESET Input Timing

SERIAL AC TIMING CHARACTERISTICS

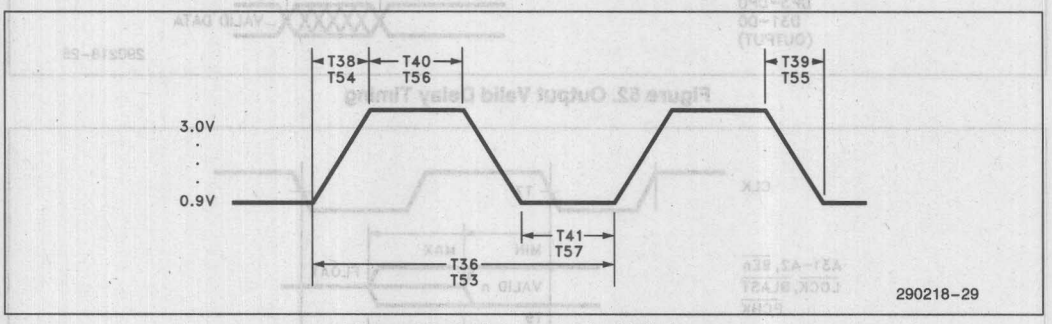


Figure 56. Serial Input Clock Timing

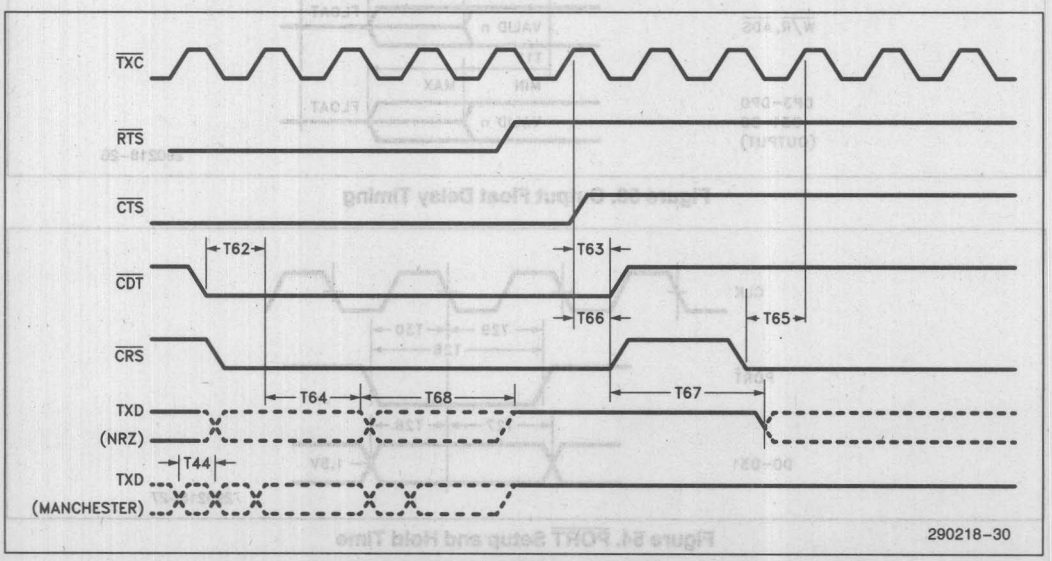


Figure 57. Transmit Data Waveforms

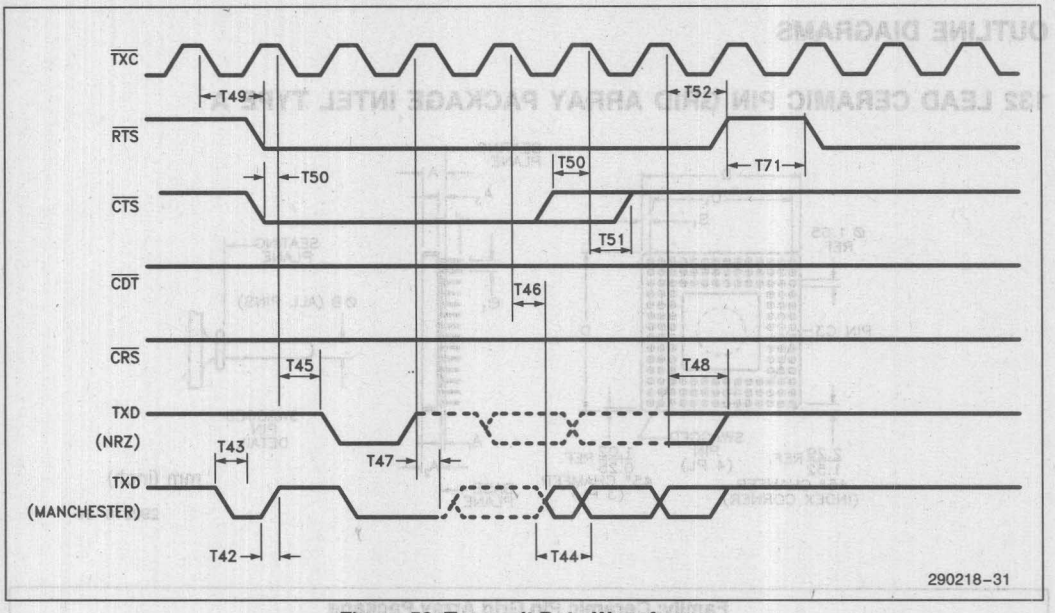


Figure 58. Transmit Data Waveforms

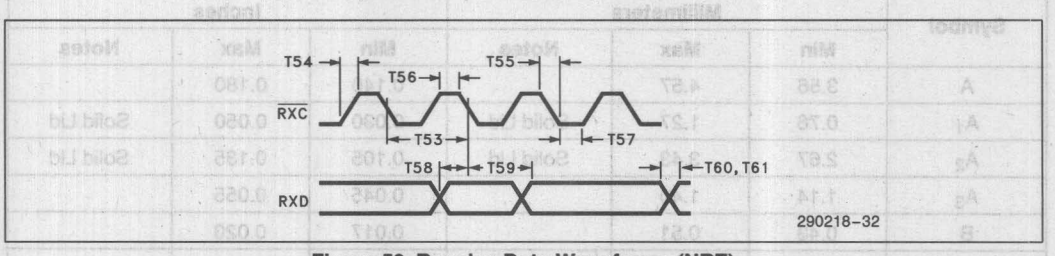


Figure 59. Receive Data Waveforms (NRZ)

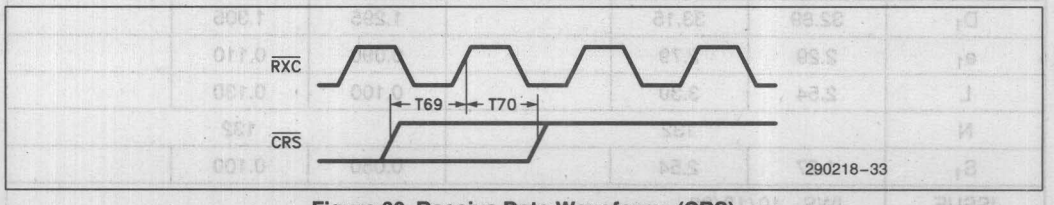
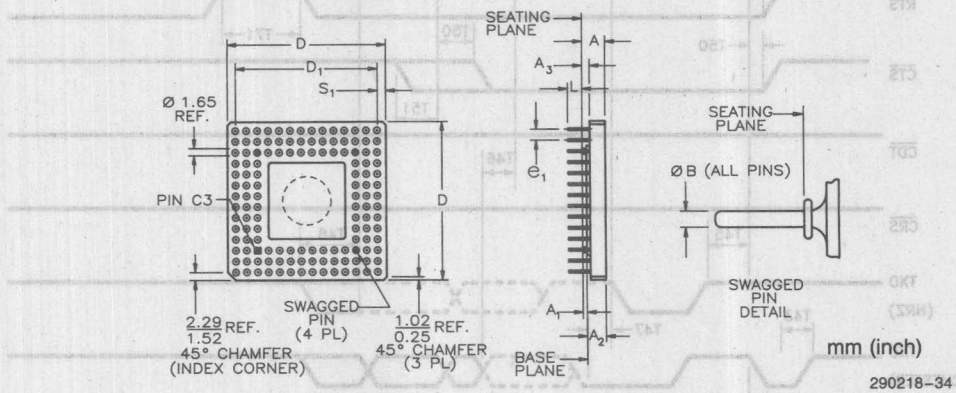


Figure 60. Receive Data Waveforms (CRS)

7

OUTLINE DIAGRAMS

132 LEAD CERAMIC PIN GRID ARRAY PACKAGE INTEL TYPE A



Family: Ceramic Pin Grid Array Package						
Symbol	Millimeters			Inches		
	Min	Max	Notes	Min	Max	Notes
A	3.56	4.57		0.140	0.180	
A_1	0.76	1.27	Solid Lid	0.030	0.050	Solid Lid
A_2	2.67	3.43	Solid Lid	0.105	0.135	Solid Lid
A_3	1.14	1.40		0.045	0.055	
B	0.43	0.51		0.017	0.020	
D	36.45	37.21		1.435	1.465	
D_1	32.89	33.15		1.295	1.305	
e_1	2.29	2.79		0.090	0.110	
L	2.54	3.30		0.100	0.130	
N	132			132		
S_1	1.27	2.54		0.050	0.100	
ISSUE	IWS 10/12/88					

Intel Case Outline Drawings
Plastic Quad Flat Pack (PQFP)
0.025 Inch (0.635mm) Pitch

Symbol	Description	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
N	Leadcount	68		84		100		132		164		196	
A	Package Height	0.160	0.170	0.160	0.170	0.160	0.170	0.160	0.170	0.160	0.170	0.160	0.170
A1	Standoff	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030
D, E	Terminal Dimension	0.675	0.685	0.775	0.785	0.875	0.885	1.075	1.085	1.275	1.285	1.475	1.485
D1, E1	Package Body	0.547	0.553	0.647	0.653	0.747	0.753	0.947	0.953	1.147	1.153	1.347	1.353
D2, E2	Bumper Distance	0.697	0.703	0.797	0.803	0.897	0.903	1.097	1.103	1.297	1.303	1.497	1.503
D3, E3	Lead Dimension	0.400 REF		0.500 REF		0.600 REF		0.800 REF		1.000 REF		1.200 REF	
D4, E4	Foot Radius Location	0.623	0.637	0.723	0.737	0.823	0.837	1.023	1.037	1.223	1.237	1.423	1.437
L1	Foot Length	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030	0.020	0.030
Issue	IWS Preliminary 12/12/88												INCH

Symbol	Description	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
N	Leadcount	68		84		100		132		164		196	
A	Package Height	4.06	4.32	4.06	4.32	4.06	4.32	4.06	4.32	4.06	4.32	4.06	4.32
A1	Standoff	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76
D, E	Terminal Dimension	17.15	17.40	19.69	19.94	22.23	22.48	27.31	27.56	32.39	32.64	37.47	37.72
D1, E1	Package Body	13.89	14.05	16.43	16.59	18.97	19.13	24.05	24.21	29.13	29.29	34.21	34.37
D2, E2	Bumper Distance	17.70	17.85	20.24	20.39	22.78	22.93	27.86	28.01	32.94	33.09	38.02	38.18
D3, E3	Lead Dimension	10.16 REF		12.70 REF		15.24 REF		20.32 REF		25.40 REF		30.48 REF	
D4, E4	Foot Radius Location	15.82	16.17	18.36	18.71	21.25	21.25	25.89	26.33	31.06	31.41	36.14	36.49
L1	Foot Length	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76	0.51	0.76
Issue	IWS Preliminary 12/12/88												mm

7

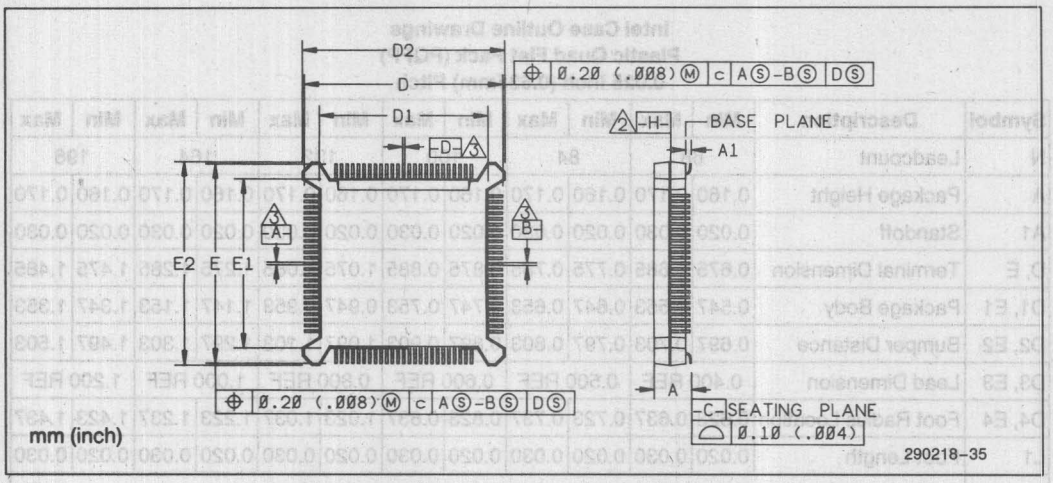


Figure 61. Principal Dimensions and Datums

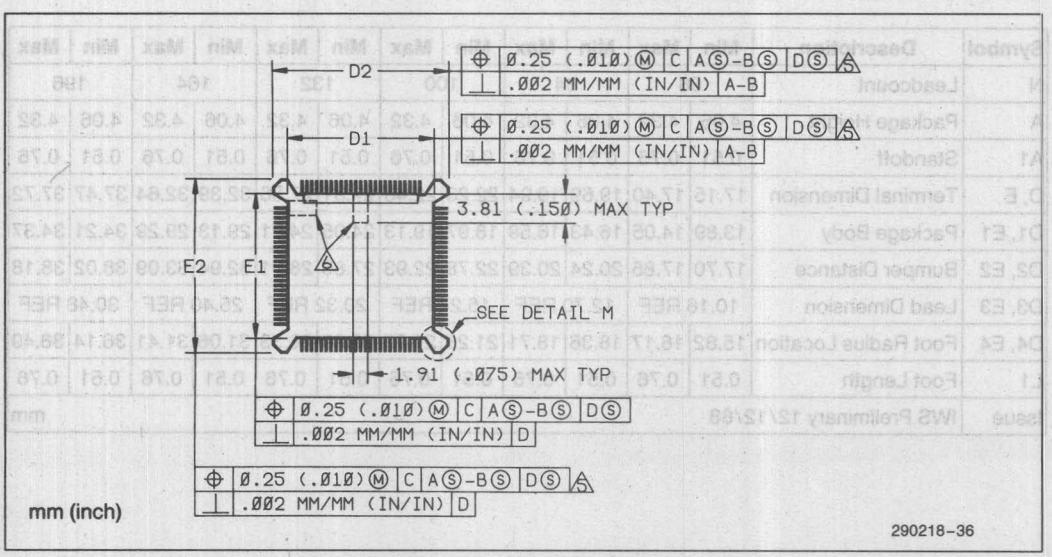


Figure 62. Molded Details

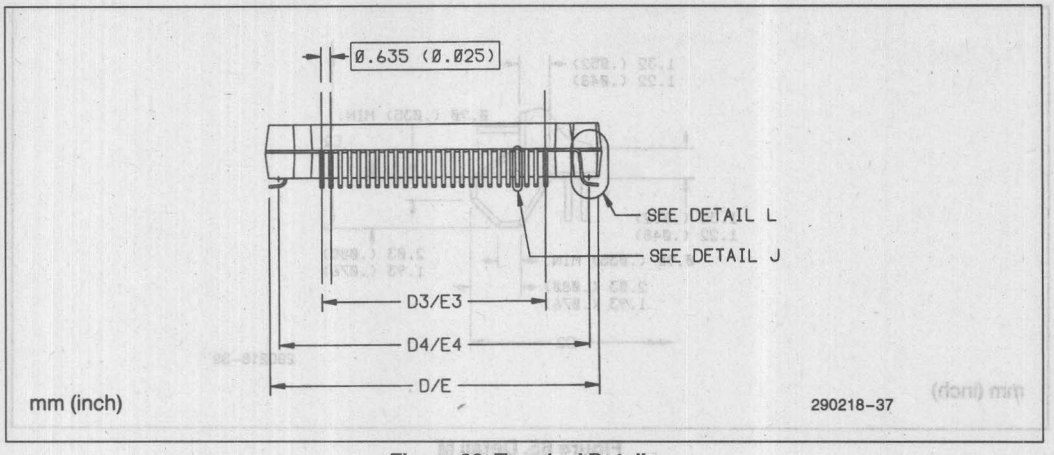


Figure 63. Terminal Details

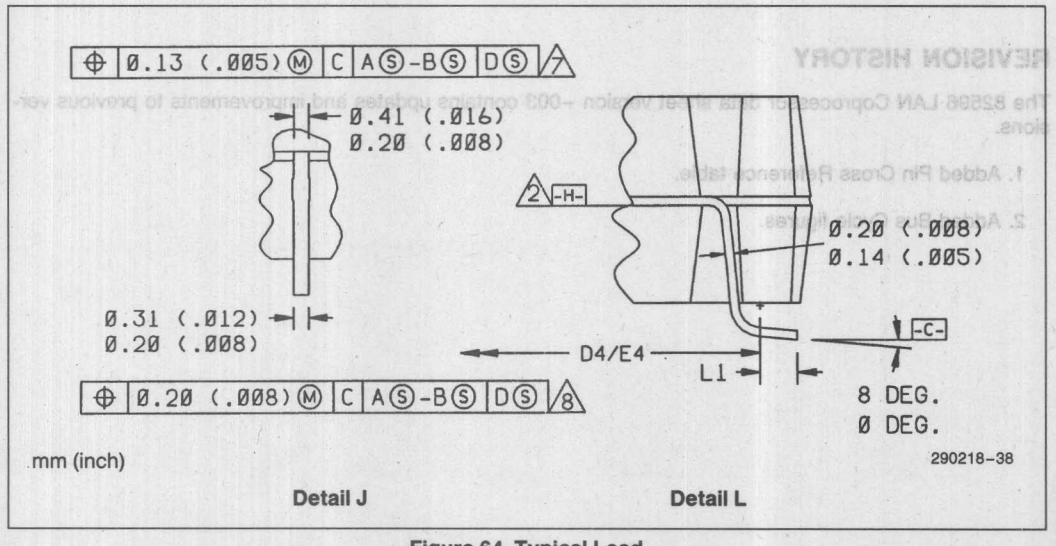
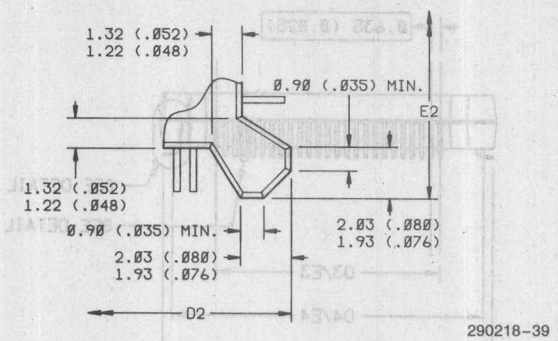


Figure 64. Typical Lead



mm (inch)

Figure 65. Detail M

REVISION HISTORY

The 82596 LAN Coprocessor data sheet version -003 contains updates and improvements to previous versions.

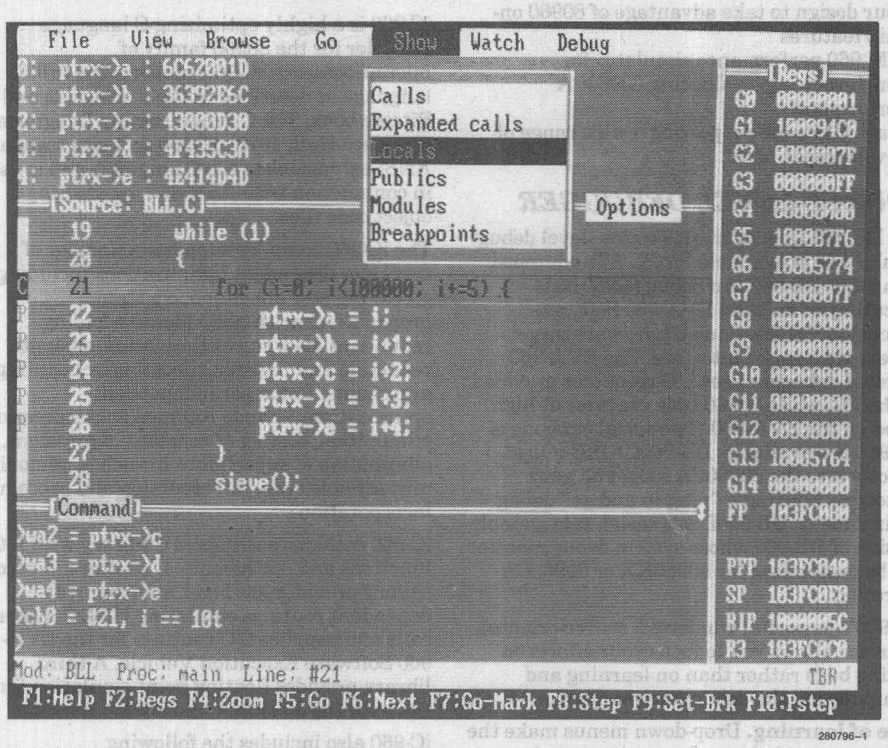
1. Added Pin Cross Reference table.
2. Added Bus Cycle figures.

80960 Development Support Tools

8

8 80960 Development Support Tools

80960 SOFTWARE DEVELOPMENT SUPPORT



280796-1

COMPREHENSIVE SOFTWARE DEVELOPMENT SUPPORT FOR 80960 EMBEDDED APPLICATIONS

The most comprehensive development support for Intel's powerful 80960 microprocessor comes, naturally, from Intel. We have every tool you need, from debugger to performance simulator, to help you get started immediately on your 80960 design. All the tools described here were designed specifically for members of the 80960 family, allowing you to take full advantage of their RISC-based design. And all are supported on a variety of hosts, including PCs, VAX* minicomputers, HP* and Sun* workstations, so you can work in a familiar environment. You can even buy 80960 software tools in handy starter kits that make development more economical.

SOFTWARE TOOLS AVAILABLE

- Windowed, interactive, source-level DB-960 debugger
- iC-960 highly optimizing C language compiler for high-level language software development
- ASM-960 macro assembler for developing and tuning speed-critical code
- EVA-960KB plug-in execution board for benchmarking performance, evaluating architecture, and developing and debugging application code on a PC AT*.

*PC AT is a registered trademark of International Business Machines Corporation.
VAX/VMS and MicroVAX/VMS are trademarks of Digital Equipment Corporation.
VAX/ULTRIX and MICROVAX/ULTRIX are trademarks of Digital Equipment Corporation.
Sun 3 is a trademark of Sun Microsystems.
HP9000 is a trademark of Hewlett Packard.
AboveBoard is a trademark of Intel Corporation.

November 1990
Order Number: 280796-007

8

FEATURES

- GEN-960 system generator for initializing your design to take advantage of 80960 on-chip features
- SIM-960 performance simulator for benchmarking/evaluating 80960CA performance
- Starter kits for supporting a wide range of development needs

SOURCE-LEVEL DEBUGGER

The DB-960 Debugger with source-level debug capabilities is available for PC ATs equipped with DOS. DB-960 can debug 80960 code executing on an Intel EVA-960 Software Execution Vehicle or on a hardware target system via a serial interface. The EVA-960 targeted debugger uses I/O resources provided by the PC, while 80960 code executes at high speed on the EVA-960. Two serial versions of DB-960 are available. DB-960CADIC plugs directly into the 80960CA socket on your prototype, offering a "plug-in and go" debug environment. DB-960D is a serial, retargetable version of DB-960 whose system debug monitor can be customized for 80960KX or 80960CA operation.

DB-960's powerful, windowed, source-oriented interface allows you to focus your efforts on finding bugs rather than on learning and manipulating the debug environment.

Ease of learning. Drop-down menus make the debugger easy to learn for new or casual users. A command line interface allows direct command entry for solving more complex problems, improving productivity of knowledgeable users.

Extensive debug modes. You can set conditional breakpoints, pass points, and temporary breakpoints as needed.

See into your program. Using pull-down menus or function keys, you can browse source and Call stacks, monitor processor registers, view screen output, and watch the values of variables change.

Full debug symbolics for maximum productivity. You need not know whether a variable is an unsigned integer, a real, or a structure: the debugger displays program variables in their respective type formats.

iC-960 COMPILER

iC-960 is a highly optimizing C language compiler for the 80960 family of microprocessors. iC-960 supports the full C language as described in the Kernighan and Ritchie book, The C Programming Language (Prentice-Hall, 1978). iC-960 includes standard ANSI extensions to the C language and is used in conjunction with ASM-960 for creating object code files.

The iC-960 compiler supports a number of processor dependent optimizations including global register allocation, constant propagation, arithmetic identity folding, redundant load/store elimination, strength reduction and register allocation/scheduling of arguments. Processor independent optimizations include common sub-expression elimination, folding of constant expressions, elimination of superfluous branches, removing unreachable code, tail recursion and procedure incorporation.

iC-960 includes a standard C library with I/O functions and mathematical routines. A second library provides low level, environment-dependent routines emulating UNIX* system calls and supplies I/O routines for the EVA-960 Software Execution Vehicle. A third library provides floating point emulation for use with the 80960KA and 80960CA.

iC-960 also includes the following enhancements for embedded application development:

Programs may be easily placed in ROM.

Memory-mapped I/O allows high-level language access to application-specific input and output.

In-line assembly simplifies the integration of C language and assembly code for speed-critical functions.

Floating point support produces in-line code to take full advantage of the floating point capability of the 80960KB and 80960MC.

The DOS-hosted version requires a 2MB Above™Board. The EVA960-hosted version requires the 4MB board (EVA960KB4MB) and provides a significant compile-time speed improvement over the DOS-hosted version.

Symbolic debugging of source code for iC-960 and ASM-960 is provided by the DB-960 Source Level Debugger.

FEATURES

ASM-960 MACRO ASSEMBLER

The ASM-960 macro assembler is used to fine-tune sections of code for peak program execution speed on the 80960KA, 80960KB, 80960MC, and 80960CA. ASM-960 does this by giving you absolute control over program instructions. In addition to the assembler and macro preprocessor, ASM-960 includes several utilities for application program maintenance and debug:

- LINKER provides incremental program linking/locating and link-time optimization.
- ARCHIVER allows you to build reusable function libraries for applications.
- DISASSEMBLER produces assembly language from object files.
- SYMBOL DUMPER provides symbolic information from a program file for facilitating low-level debug.
- ROM IMAGE BUILDER produces a hex file suitable for PROM programmers.
- MACRO PREPROCESSOR provides code generation flexibility and improves code readability, reducing maintenance costs.

ASM-960 also supports the additional instructions supplied by the 80960CA, including branch prediction. A Floating Point Arithmetic Library (FPAL) is included for the 80960KA and 80960CA and eliminates the need to develop your own floating point code.

FEATURES

EVA-960KB4MB SOFTWARE EXECUTION VEHICLE

The EVA-960KB4MB is a software execution vehicle for the 80960KA/KB microprocessor. It is a single PC AT plug-in board which provides easy and convenient architecture evaluation and benchmarking, as well as software development. Used in conjunction with the C-960E Compiler, the EVA-960KB4MB execution vehicle can compile C code 3-5 times faster than the PC AT. The EVA-960KB4B contains the following:

- 4MB of one wait-state program memory (DRAM)
- 64K bytes of zero wait-state program memory (SRAM)
- Three-channel programmable interval timer
- Hosted debug monitor which supports two hardware and 64 software breakpoints, single-step program execution, register and memory access, program download and upload.
- DOS access libraries that allow: screen display, keyboard input, read and write disk files, and the ability to spawn a DOS process that could communicate with serial or parallel I/O.
- 20 MHz operation, allowing software to operate at full speed of 80960KB

EVA-960KB4MB also operates with the DB-960 Source Level Debugger for code development/debug prior to target system availability.

GEN-960 SYSTEM GENERATOR

The 80960 System Generator (GEN-960) helps you set up data structures for standalone, embedded applications that use the on-chip features of the 80960 architecture. GEN-960 is used with other 80960 tools to generate and refine ROM or RAM code. GEN-960 supplies a set of command and template files containing assembly code and linker control commands to set up processor control blocks, inter-agent communication mechanisms, system procedure tables, and other requirements for initialization. The result is a batch file containing all the commands needed to compile, assemble and link the final target system.

- Improves engineering productivity by automating the compilation, assembly and linking process
- Supplies sample initialization code, reducing programming time
- Saves engineering time by simplifying the task of initializing each processor for on-chip capabilities

SIM-960CA PERFORMANCE SIMULATOR

The SIM-960CA Performance Simulator emulates the instruction set of the 80960CA microprocessor. You can specify wait-states and clock speed assuring accurate simulation of code execution on your target system. Using SIM-960CA's trace capability, you can trace instruction execution and read/write activity at a particular location. Timing profiles of 80960CA operations are accurate to within plus or minus 5%. Accurate estimates of actual 80960CA code performance can thus be made without an 80960CA-based target.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, *iComments* publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

SOFTWARE DEVELOPMENT TOOLS

ASM960	Assembler package containing the assembler, linker/loader, macro preprocessor, archiver, ROM image builder, other object file utilities, and the 80960KA/CA floating point arithmetic library.

80960 SOFTWARE DEVELOPMENT SUPPORT

C960 Optimizing C Compiler, with ANSI extensions for embedded control applications; contains standard STDIO libraries and in-line assembly capability. DOS version requires 2 Mbyte AboveBoard.

GEN960 80960 System Generation software automates the compilation, assembly and linking process. Simplifies usage of 80960 sophisticated features.

SIM960CA Performance Simulator software emulates the 80960CA instruction set allowing performance benchmarking and "fine tuning" prior to hardware prototype availability.

DB960KBDEVA Source Level Debugger software for the 80960KB/KA with powerful debug capabilities including conditional breakpoints, source and Call stack browsing, memory/register display and modification, and ability to watch variables change value. Requires EVA-960KB4MB Software Execution Vehicle. For PC AT hosted systems only.

DB960D Retargetable Source Level Debugger software for 80960KA/KB or CA processors resident on serially-interfaced hardware prototype systems. Includes customizable system debug monitor and serial interface protocol specifications. For PC AT hosted systems only.

DB960CADIC In-Circuit Source Level Debugger for 80960CA only. Includes small card with 80960CA processor, system debug monitor and serial interface. Plugs into 80960CA socket on hardware prototype system. "Ready to use" equivalent of DB960D. For PC AT hosted systems only.

EVA960KB4MB Software Execution Vehicle for 80960KA/KB. Includes 4M byte of on-board memory, system debug monitor and code download software. Can be used with C960E Compiler to accelerate compilation 3-5X over PC AT alone. Required by DB960KBDEVA.

8

80960 SOFTWARE DEVELOPMENT SUPPORT

ARCHITECTURE EVALUATION STARTER KITS

960SKit3 Contains ASM960D Assembler and iC960D Compiler.

960SKit3AB Same as 960SKit3 plus Intel Above™Board with 2M byte memory.

960SKit4 Contains ASM960M Assembler and C960M Compiler, hosted on MicroVAX/VMS.

960SKit5 Contains ASM960V Assembler and C960V C Compiler, hosted on VAX/VMS.

960SKit6 Fast development kit contains EVA960KB4MB Software Execution Vehicle and C960E Software Execution Vehicle hosted C Compiler.

960SKit7 Same as 960SKit6 plus ASM960D Assembler.

960SKit8 Contains ASM960U Assembler and C960U C Compiler, hosted on Sun 3.

DB960KIT1 Kit contains DB-960KBDEVA (KB version of DB-960 used with EVA-960) and EVA960KB4MB Software Execution Vehicle. Requires ASM960D and C960D or C960E and a PC AT with 640K memory.

DB960KIT2 Kit contains DB-960KBDEVA (KB version of DB-960 used with EVA-960), EVA960KB4MB Software Execution Vehicle, ASM960D and C960E. Requires PC-AT with 640K memory.

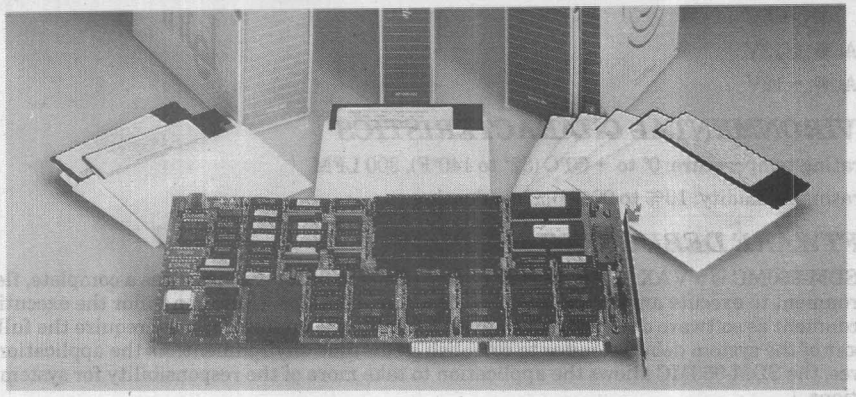
DB960KIT3 Kit contains DB-960D (serial version of DB-960 supporting 80960KX and 80960CA, operating on PC AT/DOS), ASM960D and C960D. Requires PC AT with 640K memory.

DB960KIT7 Kit contains DB-960CADIC (in-circuit version of DB-960 supporting 80960CA, operating on PC AT/DOS), ASM960D and C960D. Requires PC AT with 640K memory.

For more information or the number of your nearest Intel sales office, call 800-548-4725 (good in the U.S. and Canada).

Product Code to order, by Host

Product Category	PC AT/DOS	EVA-960KB	VAX/VMS	μVAX/VMS	Sun 3/ UNIX	HP9000/ HP-UX	VAX/ ULTRIX	μVAX/ ULTRIX
Assembler	ASM960D	—	ASM960V	ASM960M	ASM960U	ASM960H	ASM960VX	ASM960MX
C Compiler	C960D	C960E	C960V	C960M	C960U	C960H	C960VX	960VX
System Gen	GEN960D	—	GEN960V	GEN960M	GEN960U	GEN960H	—	—
KX Debugger	DB960KBDEVA	—	—	—	—	—	—	—
	DB960D	—	—	—	—	—	—	—
CA Debugger	DB960CADIC	—	—	—	—	—	—	—
	DB960D	—	—	—	—	—	—	—
CA Simulator	SIM960CAD	—	SIM960CAV	SIM960CAM	SIM960CAU	SIM960CH	—	—



280879-1

80960MC-BASED TARGET SYSTEM SUPPORTING EARLY SOFTWARE DEVELOPMENT AND BENCHMARKING

EXV-960MC is a software execution vehicle designed to support 80960MC-based designs. Users can use the EXV-960MC board to execute and debug their application software before a functional hardware prototype is available. The EXV-960MC is also designed with programmable waitstate SRAM to support benchmarking activities. The EXV-960MC is supported by the complete set of Intel C, assembler and Ada code generation tools. Both of the VAX/VMS*-hosted 80960MC software debuggers, the SDM-960MC system debug monitor and the Ada-960MC source-level debugger, can be used for debugging software running on the EXV-960MC.

EXV-960MC includes a Multibus I form factor board and a set of SDM-960MC target monitor EPROMS. The SDM-960MC and the Ada-960MC debugger are preconfigured to support the EXV-960MC execution environment. Designers can select the software debugger best suited to their development needs. The Ada-960MC debugger is a source-level symbolic debugger which provides a productive debugging environment for Ada applications. The SDM-960MC debug monitor offers a complete debugging facility for applications written in C, assembler or Ada.

*VAX/VMS is a trademark of Digital Equipment Corp.

SDM-960MC RETARGETABLE SYSTEM DEBUG MONITOR

FEATURES

- 25 MHz 80960MC processor
- 256 Kbytes of (0,0,0,0) programmable wait-state SRAM
- 4 Mbytes dual-ported (3,1,1,1) wait-state DRAM
- iSBX™ interface
- Two serial ports, one bi-directional parallel port
- 8254 programmable interval timer
- 8259A programmable interrupt controller

ELECTRICAL CHARACTERISTICS

10 A @ +5V

50mA @ +12V

50mA @ −12V

ENVIRONMENTAL CHARACTERISTICS

Operating temperature: 0° to +60°C (32° to 140°F), 300 LFM

Operating Humidity: 10% to 90% non-condensing

SOFTWARE DEBUGGING SUPPORT

The SDM-960MC is a VAX/VMS*-hosted system debug monitor that provides a complete, flexible environment to execute and debug 80960MC-based applications. Users can tailor the execution environment as software development evolves. Initially, the application may require the full support of the system debug monitor to establish a run-time environment. As the application evolves, the SDM-960MC allows the application to take more of the responsibility for system functions.

The default execution environment of the SDM-960MC is the EXV-960MC execution vehicle. The VAX-hosted portion of the SDM-960MC debug monitor provides complete on-target debugging support through its interface with the target-resident portion of the SDM-960MC. To facilitate debugging on a user's custom target system, the SDM-960MC includes source and object files necessary to reconfigure the target monitor. SDM-960MC and other 80960MC development tools allow the developers to take full advantage of the 80960MC processor.

FEATURES

- assemble and disassemble 80960MC instructions
- single step program execution
- access to memory and processor resources
- support 64 execution breakpoints
- issue Interagent Communications (IACs)
- powerful execution trace
- serial download

HARDWARE REQUIREMENTS

- a serial interface
- 25 Kbytes of EPROM
- contiguous 50 Kbytes of RAM

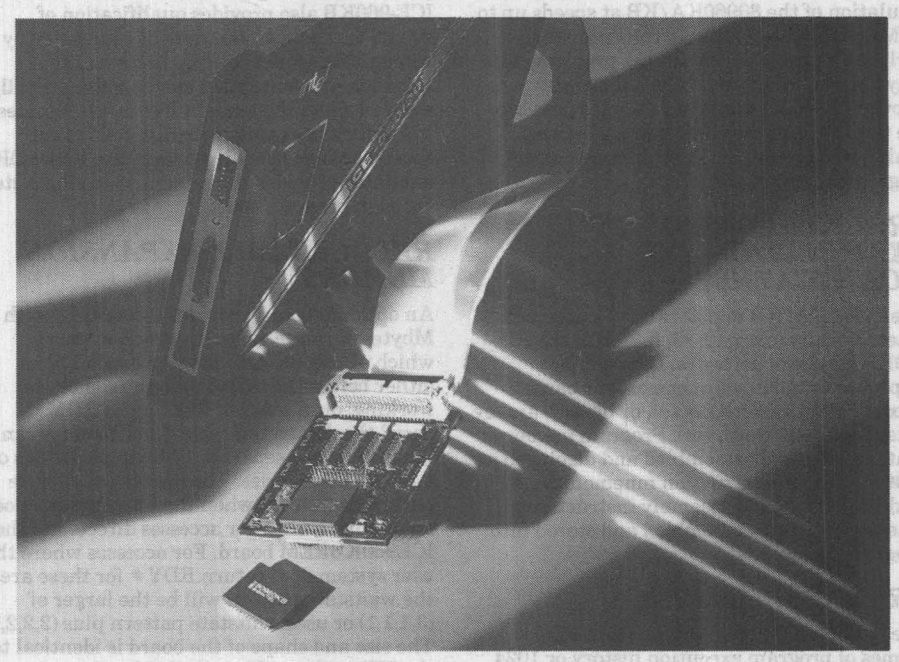
WORLDWIDE SERVICE AND SUPPORT

Intel augments its 80960 architecture family development tools with a full array of seminars, classes, and workshops; on-site consulting services and telephone support are available at all stages of development.

ORDERING INFORMATION

Product Code	Description
EXV960MC	80960MC execution vehicle (board and target EPROM)
SDM960MC	VAX, MicroVAX/VMS hosted System Debug Monitor, retargetable source is included

ICE™-960KB IN-CIRCUIT EMULATOR



280852-1

IN-CIRCUIT EMULATOR FOR THE 80960KA AND 80960KB MICROPROCESSORS

The ICE™-960KB In-Circuit Emulator delivers real-time hardware and software debugging capabilities for 80960KA/KB-based designs. Features include emulation of the 80960KA/KB microprocessors, powerful breakpoint specification, fastbreaks, optional relocatable expansion memory, two types of trace capability, large trace buffering and sophisticated human interface. The ICE-960KB In-circuit Emulator gives you unmatched control over all phases of hardware/software debug, including developing, integrating and testing, which improves development productivity and improves time to market.

FEATURES

- Real-Time Emulation of the 80960KA/KB microprocessors up to 20 MHz (25 MHz Optional)
- Full Symbolic Information relating to Code and Data
- Optional ICE960KBREM board provides 2 Mbytes of ICE memory which can overlay user ROM or RAM.
- Zero wait-state operation from user memory
- Examine and modify Memory and the 80960 Registers
- Breakpoint capabilities include: Execution Address, Instruction Type, Bus Read/Write/Access, and Data Value. Qualification of Events is based on an Occurrence Counter and an 8 state State-Machine
- Hosted on IBM PC AT or compatible
- Dynamically monitor or update program variables or memory during emulation with Fastbreaks
- 1024 Frame Trace Buffer for execution and/or Bus Trace and Time Tags
- 256 Kbytes of Memory in Standalone Self-Test (SAST) Unit

November 1990
Order Number: 280852-002

FEATURES

The ICE-960KB In-Circuit Emulator provides emulation of the 80960KA/KB at speeds up to 20 MHz (25 MHz optional), thus providing early detection of subtle timing problems that may arise at full speed. Intel's intimate knowledge of the component makes possible the tightest possible conformance between timing parameters of the emulator and the target microprocessor.

PROCESSOR/MEMORY EXAMINATION AND MODIFICATION

The 80960KA/KB registers can be accessed mnemonically (e.g. g12, r5, fp3) with the ICE-960KB emulator software. Data can be displayed or modified in one of four bases (hexadecimal, decimal, octal, or binary) and by data type (byte, word, etc). Program memory contents can be disassembled and displayed as 80960 assembly instruction mnemonics. Additionally, 80960 assembly instruction mnemonics can be assembled and stored into program memory.

PROGRAM TRACING

The ICE-960KB emulator can store 1024 frames of program execution history or 1024 frames of the 80960KA/KB address/data bus activity in the trace buffer. Each frame of program execution contains a discontinuity address (branch, call, return, etc) and a time-tag. This information can be used to reconstruct a history of the program execution. With the execution trace option enabled, the ICE-960KB will run at less than full speed. Each trace frame of bus cycles contains one complete bus burst trace. Collection of trace information is controlled by a logic analyzer type moving trace window and by bus access type.

EVENT RECOGNITION (BREAKPOINT CONTROL) AND EMULATION CONTROL

ICE-960KB provides comprehensive event recognition capabilities including: two hardware and thirty-two software breakpoints for instruction execution breakpoints, and use of the internal debug registers to recognize execution of certain instruction types such as branch or call instructions. Bus analysis logic provides recognition of external bus addresses qualified by read, write, or access type as well as data values which may be entered as masked values. Two synchronization lines are provided for recognition of external events. ICE-960KB also provides qualification of events based on an occurrence counter or by a recognition sequence of up to 8 events. Additionally, emulation can be automatically stopped when the trace buffer is full. Besides the ability to execute program code at full speed between specified points, the ICE-960KB emulator provides the capability to single-step through program code.

RELOCATABLE EXPANSION MEMORY

An optional board provides ICE-960KB with 2 Mbytes of relocatable expansion memory which allows users to develop applications either before the target system memory is working, or in place of ROM or EPROM to speed the debugging cycle. This memory can be mapped in two separate 1 Mbyte partitions on 1 Mbyte boundaries. The memory waitstate pattern is (3,1,1,1) when the users system does not return RDY# for accesses directed to the ICE960KBREM board. For accesses where the user system does return RDY# for these areas, the waitstate pattern will be the larger of (3,1,1,1) or user waitstate pattern plus (2,2,2,2). The size and shape of the board is identical to the ICE probe and is installed between the probe and the user's target system when in use. The memory configuration can be mapped via either an ICE MAP command or via switches on the ICE960KBREM board.

The ICE-960KBREM card adds some constraints when used with the ICE in a users target system. First, users should qualify bus drivers/buffers with DEN# in order to eliminate potential bus conflict between REM960 and their target memory. Second, the 1M Byte partition size can not be reduced and may effect the design of the users memory subsystem. Third, ICE960KBREM delays the ADS# and DEN# signals by 5 ns (typical) and delays the RDY# signal by 2 ns (typical). Fourth, it adds loading, capacitance, and power requirements as shown in tables 3 and 4.

STANDALONE OPERATION

Product software can be developed and debugged prior to and independent of hardware availability with the Standalone Self Test unit (SAST), which contains 256 Kbytes of two wait-state program memory. The SAST also provides diagnostic testing to assure full functionality of the ICE-960KB emulator.

intel

FEATURES

VERSATILE AND POWERFUL HOST SOFTWARE

ICE-960KB provides an easy-to-use human interface which utilizes color and pull-down menus to complement a powerful command set. The software includes: an on-line help facility, a dynamic command entry and syntax guide, screen oriented editor, assembler and disassembler, input/output redirection, command piping, DOS command entry, and the ability to customize the command set via debug procedures and literal definitions.

DEBUG PROCEDURES AND LITERALS

Debug procedures (PROCs) are user-defined groups of ICE-960KB emulator commands. They can be stored on disk and recalled during later debugging sessions. PROCs can be used to simplify the process of debugging by grouping repetitive emulator commands, which can then be accessed by typing the name of the PROC. Literals are user-defined abbreviations for whole or partial ICE-960KB emulator commands. Literals are a shorthand method of customizing the emulator commands to fit your needs and preferences.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support, and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, "*iComments*" publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

SPECIFICATIONS

HOST REQUIREMENTS

IBM PC AT (minimum requirements) with 640 KB of conventional memory
1 MB of RAM (Lotus, Intel, Microsoft expanded memory specification)
20 MB Fixed Disk
At least one 5-¼" Floppy Disk drive
A serial interface
DOS Operating system (version 3.2 or later excluding 4.x)

REQUIRED SYSTEM RESOURCES

The ICE-960KB emulator requires the following: a) exclusive use of the 80960KA/KB's on-chip debug registers and b) a minimum of 256 bytes of target system RAM used to flush the 80960 local registers.

MECHANICAL SPECIFICATIONS

TABLE 1. ICE-960KB Emulator Physical Characteristics

Unit	Width		Height		Length		Weight	
	Inches	cm	Inches	cm	Inches	cm	lbs	kg
Control unit	10.5	26.7	1.5	3.8	16.0	40.6	6.0	2.72
Processor module*	3.8	9.6	1.5	3.8	5.0	12.7		
SAST	6.0	15.2	2.0	5.1	8.0	20.3	3.5	1.59
OIB	3.8	9.6	.9	2.3	5.1	13.0		
Power supply	2.8	7.1	4.2	10.7	11.0	27.9	4.7	2.14
User cable					22.0	55.9		
Serial cable					12.0ft.	3.66m		

*measurement includes target adaptor

8

SPECIFICATIONS

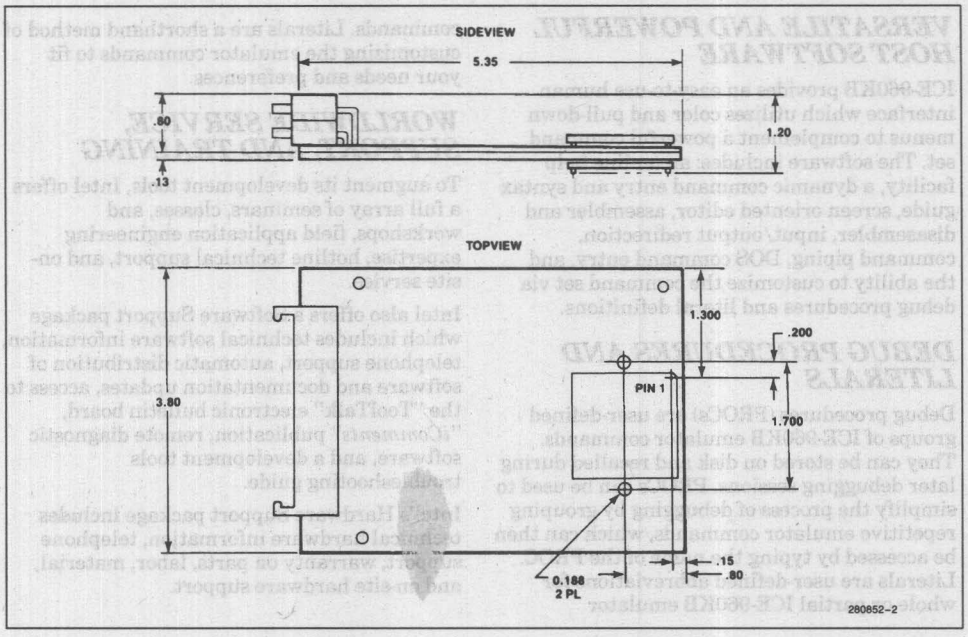


Figure 1: Processor Module Dimensions

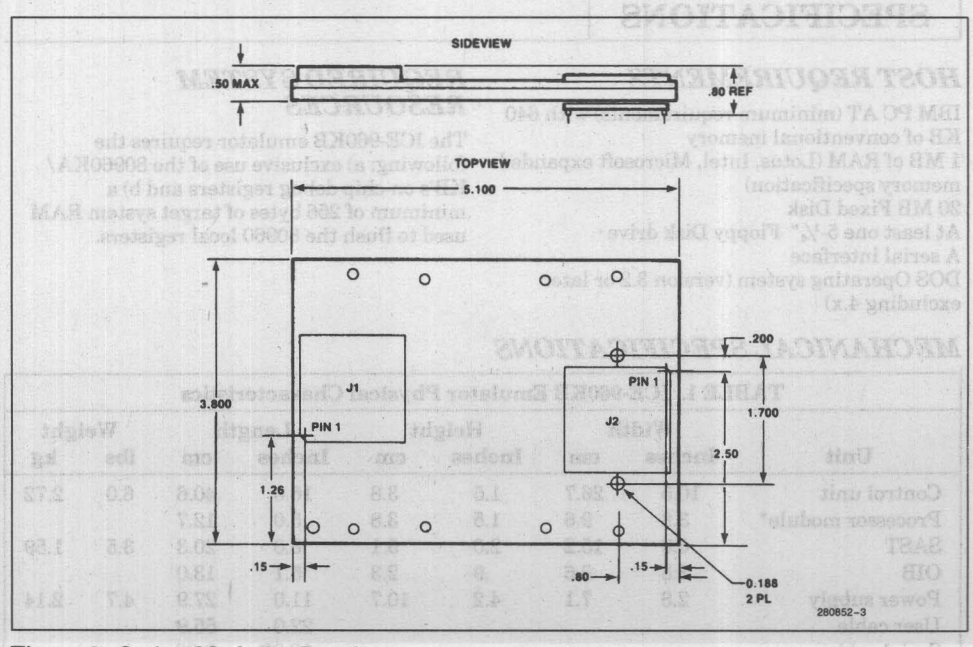


Figure 2: Optional Isolation Board

SPECIFICATIONS

ELECTRICAL SPECIFICATIONS

SYNC Line Specification

The SYNCIN line must be valid for at least one instruction cycle because it is only sampled on instruction boundaries. The SYNCIN line is a standard TTL input. The SYNCOUT line is driven by a TTL open collector with a 4.75K-ohm pull-up resistor.

TABLE 2. AC Specifications With The OIB Installed

Symbol*	Parameter	Minimum	Maximum
t2	clock low time	t2+1nS	
t3	clock high time	t3+1ns	
t6	output valid delay		
	A/D 0:31	t6+8ns	t6+16Ns
	DT/R#, DEn#,		
	BE0-3#, ADS#,		
	W/R#	t6+7nS	t6+14ns
	HLDA, CACHE,		
	LOCK#, INTA#	t6+6ns	t6+8nS
	ALE#	t6+10nS	t6+20nS
t7	ALE# width	t7−6.5nS	
t8	ALE# disable delay	t8+nS	t8+14nS
t9	output float delay		
	A/D 0:31	t9+5nS	t9+22nS
	DT/R#, DEN#,		
	BE0-3#, ADS#,		
	W/R#	t9+7nS	t9+15ns
	HLDA, CACHE,		
	LOCK#, INTA#	t9+6nS	t9+8nS
t10	input setup 1		
	A/D 0:31	t10+2nS	
	BADAC#, INT0-3#		
	deassertion	t10+14nS	
t11	input hold		
	A/D 0:31, HOLD	t11+6nS	
	BADAC#, INT0-3#,		
	READY#	t11+7nS	
t16	reset setup time	t16+6	

*symbol refers to 80960KB specification

AC/DC Specifications

The Optional Isolation Board (OIB) isolates the ICE-960KB probe from an untested user target system. When the OIB is in use, the ICE-960KB AC and DC specifications differ from the 80960KA/KB microprocessor as shown below. When the OIB is not installed, the ICE-960KB specifications are identical to those of the 80960KA/KB component.

TABLE 3. ICE-960KB Emulator DC Specifications

Symbol*	Parameter	Maximum
PM-Icc	Supply current with 80960KB-20	1400mA
OIB-Icc	Supply current	PM-Icc + 1100mA
REM-Icc	Supply current	PM-Icc + 1300mA (1700 Total Typical)

8

SPECIFICATIONS

TABLE 4. Additional DC Loading

Signal	(without OIB installed) Iih Maximum	Iil Maximum	(with OIB installed) Iih Maximum	Iil Maximum	(with REM installed) Iih Maximum	Iil Maximum
AD (0:31)	100 uA	0.6 mA	20 uA	−1 mA	120 uA	0.7 mA
ADS#	140 uA	1.6 mA	20 uA	−1 mA	Driven by 74AS760	
DEN#	40uA	1.0 mA	20 uA	−1 mA	w/ 4.7k pull-up	
W/R#	140 uA	1.6 mA	20 uA	−1 mA	150 uA	1.7 mA
CLK2	80 uA	2.2 mA	50 uA	−2 mA	130 uA	2.9 mA
RESET			50 uA	−2 mA	250 uA	0.3 mA
BE (0:3)#			20 uA	−1 mA	10 uA	0.1 mA
READY#			20 uA	−1 mA	750 uA	0.8 mA
ALE#			20 uA	−1 mA	20 uA	0.5 mA
DT/R#			20 uA	−1 mA		
INTO#, INT3#			20 uA	−1 mA		
INT1, INT2			20 uA	−1 mA		
BADAC#			20 uA	−1 mA		
LOCK#			20 uA	−1 mA		
HOLD			20 uA	−1 mA		
FAILURE#			20 uA	−1 mA		

POWER SUPPLY

100—120V or 220—240V (Selectable)
50—60 Hz
2 amps (AC Max) @ 120V
1 amp (AC Max) @ 240V

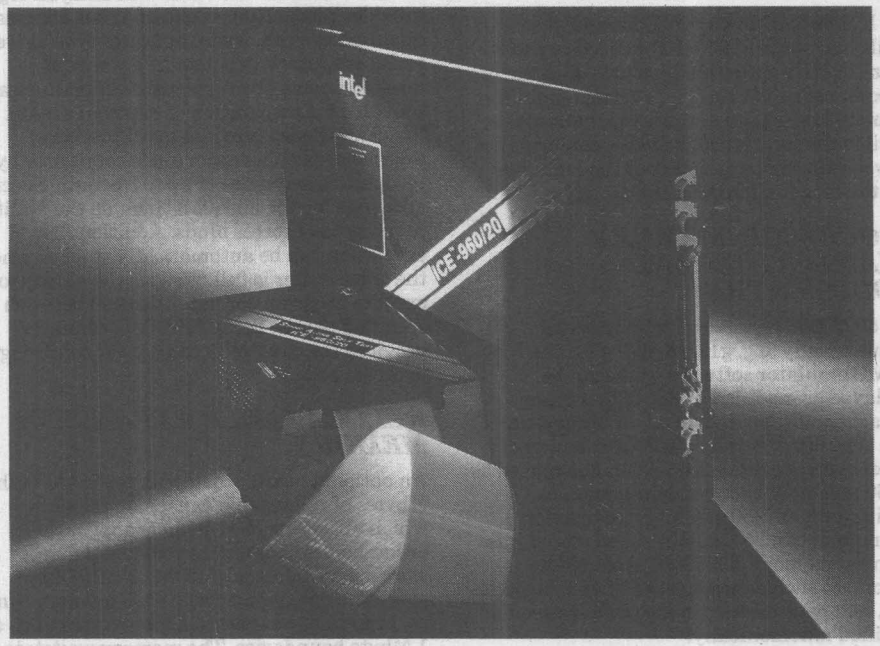
ENVIRONMENTAL CHARACTERISTICS

Operating Temperature	10°C to 40°C (50°F to 104°F)
Operating Humidity	Maximum 85% Relative Humidity, non-condensing

ORDERING INFORMATION

Order Code	Description
ICE960KB	The complete 20 MHz ICE-960KB emulator system including control unit, processor module, power supply, SAST, OIB, SAB, serial communications cable (SCOM4), IEDIT, V2.0 software. (Requires software license, Class I)
ICE960KBREM	Optional 2 MB Relocatable Expansion Memory Board

ICE™-960MC IN-CIRCUIT EMULATOR



280899-1

IN-CIRCUIT EMULATOR FOR THE 80960MC MICROPROCESSOR

The ICE™-960MC In-circuit Emulator delivers real-time hardware and software debugging capabilities for 80960MC based designs. Features include emulation of the 80960MC microprocessor, powerful breakpoint specification, fastbreaks, optional relocatable expansion memory, two types of trace capability, large trace buffering, support of virtual and physical component addressing modes, and sophisticated human interface. The ICE-960MC In-circuit Emulator gives you unmatched control over all phases of hardware/software debug, including developing, integrating and testing, which improves development productivity and speeds time to market.

FEATURES

- Real-Time Emulation of the 80960MC microprocessors up to 20 MHz (25 MHz optional)
- Full Symbolic Information Relating to Code. Data symbolics subject to some limitations in virtual addressing mode
- Optional ICE960KBREM Board Provides 2 Mbytes of ICE Memory Which Can Overlay User ROM or RAM.
- Zero wait-state operation from user memory
- Examine and modify Memory and the 80960 Registers
- Breakpoint Capabilities include: Execution Address, Instruction Type, Bus Read/Write/Access, and Data Value. Qualification of Events is Based on an Occurrence Counter and an 8 state State-Machine
- Hosted on IBM PC AT or compatible
- Dynamically monitor or update program variables or memory during emulation with Fastbreaks
- 1024 Frame Trace Buffer for execution and/or Bus Trace and time tags
- 256 Kbytes of Memory in Standalone Self-Test (SAST) Unit

8

November 1990
Order Number: 280899-001

ICE™-960MC IN-CIRCUIT EMULATOR

REAL-TIME EMULATION

The ICE-960MC In-circuit Emulator provides emulation of the 80960MC at speeds up to 20 MHz (25 MHz optional), thus providing early detection of subtle timing problems. Intel's intimate knowledge of the component makes possible the tightest conceivable conformance between timing parameters of the emulator and the target microprocessor.

PROCESSOR/MEMORY EXAMINATION AND MODIFICATION

The 80960MC registers can be accessed mnemonically (e.g. g12, r5, fp3) with the ICE-960MC emulator software. Data can be displayed or modified in one of four bases (hexadecimal, decimal, octal, or binary) and by data type (byte, word, etc). Program memory contents can be disassembled and displayed as 80960 assembly instruction mnemonics. Additionally, 80960 assembly instruction mnemonics can be assembled and stored into program memory. 80960MC system data structures such as the segment table, dispatch port, and page tables can also be accessed and modified mnemonically.

PROGRAM TRACING

The ICE-960MC emulator can store 1024 frames of program execution history or 1024 frames of the 80960MC address/data bus activity in the trace buffer. Each frame of program execution contains a discontinuity address (branch, call, return, etc) and a time-tag. This information can be used to reconstruct a history of the program execution. With the execution trace option enabled, the ICE-960MC will run at less than full speed. Each trace frame of bus cycles contains one complete bus burst trace. Collection of trace information is controlled by a logic analyzer type moving trace window and by bus access type.

EVENT RECOGNITION (BREAKPOINT CONTROL) AND EMULATION CONTROL

ICE-960MC provides comprehensive event recognition capabilities including: two hardware and thirty-two software breakpoints for instruction execution breakpoints, and use of the internal debug registers to recognize execution of certain instruction types such as branch or call instructions. Bus analysis logic provides recognition of external bus addresses qualified by read, write, or access type as well as data values which may be entered as masked values. Two synchronization lines are provided for recognition of external events. ICE-960MC also provides qualification of events based on an occurrence counter or by a recognition sequence of up to 8 events. Special additions for the 80960MC include the ability to recognize process binds. Additionally, emulation can be automatically stopped when the trace buffer is full. Besides the ability to execute program code at full speed between specified points, the ICE-960MC emulator provides the capability to single-step through program code.

RELOCATABLE EXPANSION MEMORY

An optional board provides ICE-960MC with 2 Mbytes of relocatable expansion memory which allows users to develop applications either before the target system memory is working, or in place of ROM or EPROM to speed the debugging cycle. This memory can be mapped in two separate 1 Mbyte partitions on 1 Mbyte boundaries. The memory waitstate pattern is (3,1,1,1) when the user's system does not return RDY# for accesses directed to the ICE960KBREM board. For accesses where the user system does return RDY# the waitstate pattern will be the larger of (3,1,1,1) or user waitstate pattern plus (2,2,2,2). The size and shape of the board is identical to the ICE probe and is installed between the probe and the user's target system when in use. The memory configuration can be mapped via either an ICE MAP command or via switches on the ICE960KBREM board.

The ICE-960KBREM card adds some constraints when used with the ICE in a user's target system. First, users should qualify bus drivers/buffers with DEN# in order to eliminate potential bus conflict between REM960 and their target memory. Second, the 1 Mbyte partition size can not be reduced and may effect the design of the user's memory subsystem. Third, ICE960KBREM delays the ADS# and DEN# signals by 5 nsec (typical) and delays the RDY# signal by 2 nsec (typical). Fourth, it adds loading, capacitance, and power requirements as shown in tables 3 and 4.

ICE™-960MC IN-CIRCUIT EMULATOR

STANDALONE OPERATION

Product software can be developed and debugged prior to and independent of hardware availability with the Standalone Self Test unit (SAST), which contains 256 Kbytes of two wait-state program memory. The SAST also provides diagnostic testing to assure full functionality of the ICE-960MC emulator.

VERSATILE AND POWERFUL HOST SOFTWARE

ICE-960MC provides an easy-to-use human interface which utilizes color and pull-down menus to complement a powerful command set. The software includes: an on-line help facility, a dynamic command entry and syntax guide, screen oriented editor, assembler and disassembler, input/output redirection, command piping, DOS command entry, and the ability to customize the command set via debug procedures and literal definitions.

Special software commands are provided to display, interpret, and modify the 80960MC hardware data structures including the segment table, dispatch port, process control block, and the page tables and directories.

DEBUG PROCEDURES AND LITERALS

Debug procedures (PROCs) are user-defined groups of ICE-960MC emulator commands. They can be stored on disk and recalled during later debugging sessions. PROCs can be used to simplify the process of debugging by grouping repetitive emulator commands, which can then be accessed by typing the name of the PROC. Literals are user-defined abbreviations for whole or partial ICE-960MC emulator commands. Literals are a shorthand method of customizing the emulator commands to fit your needs and preferences.

8

ICE™-960MC IN-CIRCUIT EMULATOR

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support, and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, "*iComments*" publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

SPECIFICATIONS

HOST REQUIREMENTS

IBM PC AT (minimum requirements) with 640 KB of conventional memory

- 1 MB of RAM (Lotus, Intel, Microsoft expanded memory specification)
- 20 MB Fixed Disk
- At least one 5-¼" Floppy Disk drive
- A serial interface
- DOS Operating system (version 3.2 or later excluding 4.x)

REQUIRED SYSTEM RESOURCES

The ICE-960MC emulator requires the following: a) exclusive use of the 80960MC's on-chip debug registers and b) a minimum of 256 bytes of target system RAM used to flush the 80960 local registers.

Mechanical Specifications

TABLE 1. ICE-960MC Emulator Physical Characteristics

	Width		Height		Length		Weight	
Unit	Inches	cm	Inches	cm	Inches	cm	lbs	kg
Control unit	10.5	26.7	1.5	3.8	16.0	40.6	6.0	2.72
Processor module*	3.8	9.6	1.5	3.8	5.0	12.7		
SAST	6.0	15.2	2.0	5.1	8.0	20.3	3.5	1.59
OIB	3.8	9.6	.9	2.3	5.1	13.0		
Power supply	2.8	7.1	4.2	10.7	11.0	27.9	4.7	2.14
User cable					22.0	55.9		
Serial cable					12.0 ft	3.66m		

*measurement includes target adaptor

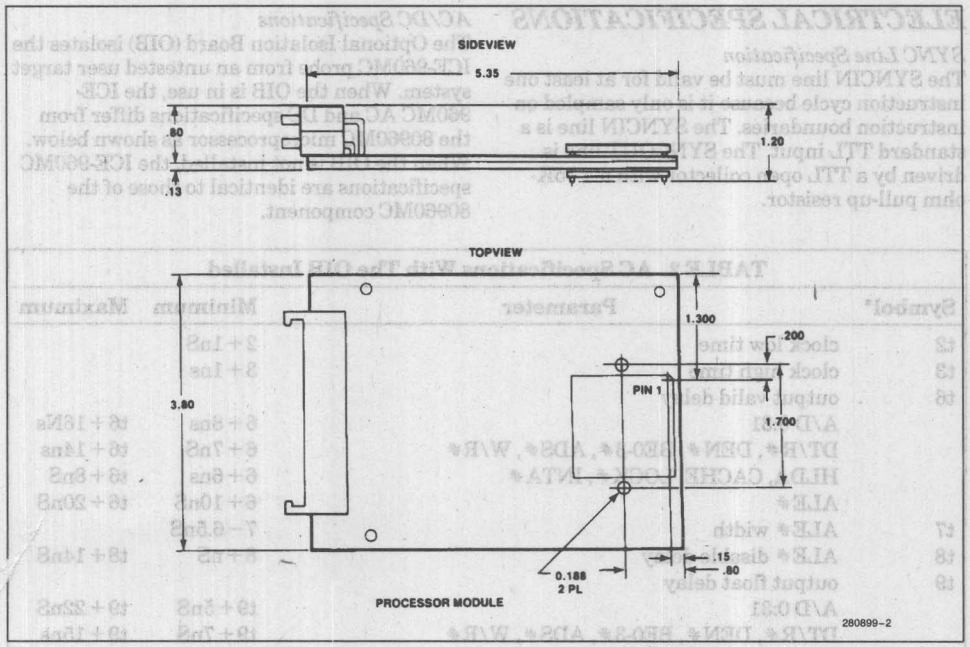


Figure 1: Processor Module

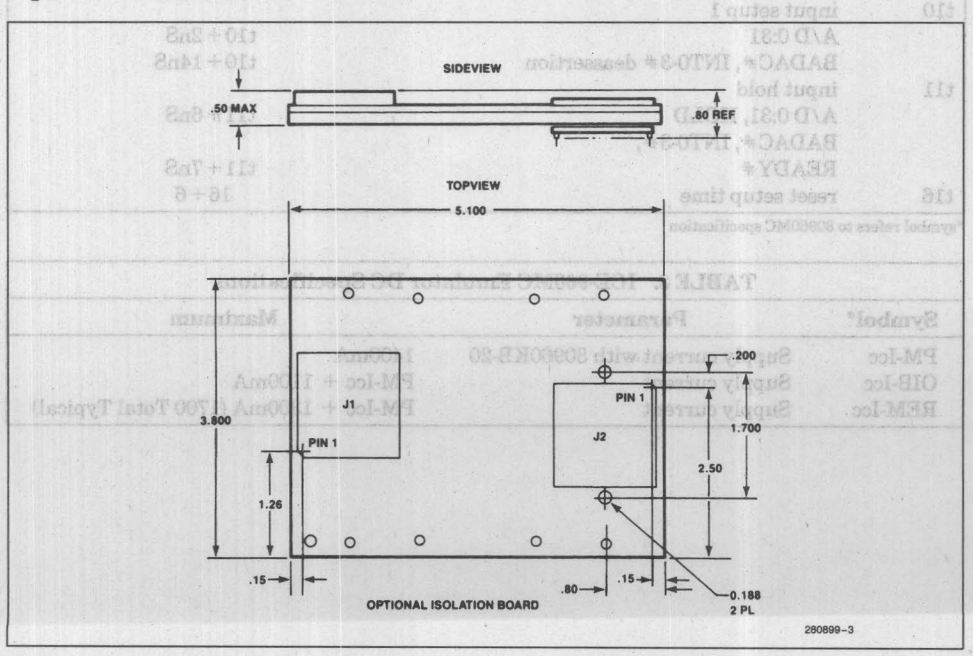


Figure 2: Optional Isolation

SPECIFICATIONS

ELECTRICAL SPECIFICATIONS

SYNC Line Specification

The SYNCIN line must be valid for at least one instruction cycle because it is only sampled on instruction boundaries. The SYNCIN line is a standard TTL input. The SYNCOUT line is driven by a TTL open collector with a 4.75K-ohm pull-up resistor.

AC/DC Specifications

The Optional Isolation Board (OIB) isolates the ICE-960MC probe from an untested user target system. When the OIB is in use, the ICE-960MC AC and DC specifications differ from the 80960MC microprocessor as shown below. When the OIB is not installed, the ICE-960MC specifications are identical to those of the 80960MC component.

TABLE 2. AC Specifications With The OIB Installed

Symbol*	Parameter	Minimum	Maximum
t2	clock low time	2+1nS	
t3	clock high time	3+1ns	
t6	output valid delay		
	A/D 0:31	6+8ns	t6+16Ns
	DT/R#, DEN#, BE0-3#, ADS#, W/R#	6+7nS	t6+14ns
	HLDA, CACHE, LOCK#, INTA#	6+6ns	t6+8nS
	ALE#	6+10nS	t6+20nS
t7	ALE# width	7−6.5nS	
t8	ALE# disable delay	8+nS	t8+14nS
t9	output float delay		
	A/D 0:31	t9+5nS	t9+22nS
	DT/R#, DEN#, BE0-3#, ADS#, W/R#	t9+7nS	t9+15ns
	HLDA, CACHE, LOCK#, INTA#	t9+6nS	t9+8nS
t10	input setup 1		
	A/D 0:31	t10+2nS	
	BADAC#, INT0-3# deassertion	t10+14nS	
t11	input hold		
	A/D 0:31, HOLD	t11+6nS	
	BADAC#, INT0-3#,		
	READY#	t11+7nS	
t16	reset setup time	16+6	

*symbol refers to 80960MC specification

TABLE 3. ICE-960MC Emulator DC Specifications

Symbol*	Parameter	Maximum
PM-Icc	Supply current with 80960KB-20	1400mA
OIB-Icc	Supply current	PM-Icc + 1100mA
REM-Icc	Supply current	PM-Icc + 1300mA (1700 Total Typical)

SPECIFICATIONS

TABLE 4. Additional DC Loading

Signal	(without OIB installed) Iih Maximum	(without OIB installed) Iil Maximum	(with OIB installed) Iih Maximum	(with OIB installed) Iil Maximum	(with REM installed) Iih Maximum	(with REM installed) Iil Maximum
AD (0:31)	100 uA	0.6 mA	20 uA	−1 mA	120 uA	0.7 mA
ADS#	140 uA	1.6 mA	20 uA	−1 mA	Driven by 74AS760	
DEN#	40 uA	1.0 mA	20 uA	−1 mA	w/ 4.7k pull-up	
W/R#	140 uA	1.6 mA	20 uA	−1 mA	150 uA	1.7 mA
CLK2	80 uA	2.2 mA	50 uA	−2 mA	130 uA	2.9 mA
RESET			50 uA	−2 mA	250 uA	0.3 mA
BE (0:3)#			20 uA	−1 mA	10 uA	0.1 mA
READY#			20 uA	−1 mA	750 uA	0.8 mA
ALE#			20 uA	−1 mA	20 uA	0.5 mA
DT/R#			20 uA	−1 mA		
INTO#, INT3#			20 uA	−1 mA		
INT1, INT2			20 uA	−1 mA		
BADAC#			20 uA	−1 mA		
LOCK#			20 uA	−1 mA		
HOLD			20 uA	−1 mA		
FAILURE#			20 uA	−1 mA		

SPECIFICATIONS

POWER SUPPLY

100–120V or 220–240V (Selectable)
50–60 Hz
2 amps (AC Max) @ 120V
1 amp (AC Max) @ 240V

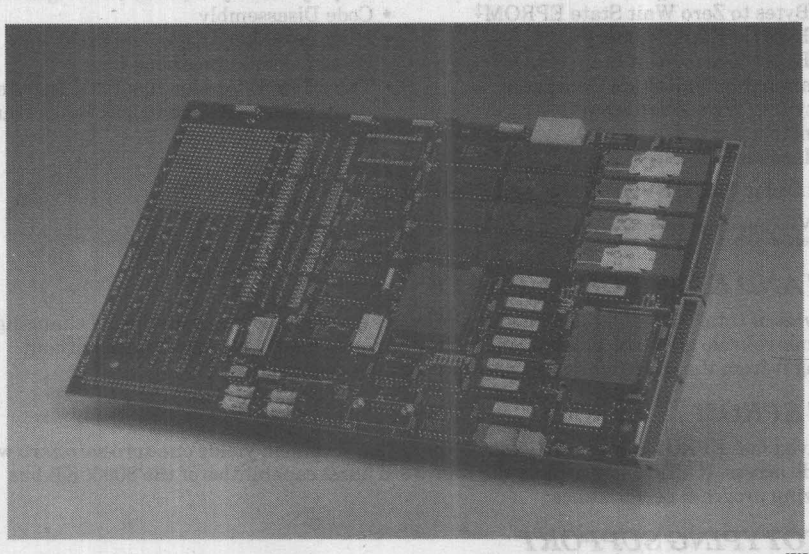
ENVIRONMENTAL CHARACTERISTICS

Operating Temperature	10°C to 40°C (50°F to 104°F)
Operating Humidity	Maximum 85% Relative Humidity, non-condensing

ORDERING INFORMATION

Order Code	Description
ICE960MC	The complete 20 MHz ICE-960MC emulator system including control unit, processor module, power supply, SAST, OIB, SAB, serial communications cable (SCOM4), IEDIT, V1.0 software. (Requires software license, Class I)
ICE960MC25P	25 MHz ICE960MC as described above
I960MCUPG	Conversion kit to convert ICE-960KB to ICE-960MC. Consists of new host and probe software, probe firmware, and manual. Requires ICE-960KB V2.0 hardware.
ICE960KBREM	Optional 2 Mbyte Relocatable Expansion Memory Board.

QT960 EVALUATION AND PROTOTYPING BOARD



270743-1

LOW COST EVALUATION TOOL

The QT960 products give you a 32-bit starter kit to begin software evaluation and hardware design at a low cost. The boards feature the 20 MHz 80960KB 32-bit embedded processor. The 80960KB has integrated floating point, instruction and register caches, and an on-chip interrupt controller. The 80960K-series are the first in a new architectural family of embedded processors from Intel built using Intel's CHMOS IV† process. These boards provide you with full access to the features of the 80960KB processor. A wire wrap prototyping area offers you easy access to board features to test your designs. Interleaved EPROM means fast execution of your code taking advantage of the 80960KB's burst bus. A programmable wait state generator simulates different memory environments useful in evaluating the performance of your code. These features make the QT960 boards useful low cost tools for the 32-bit embedded designer.

Once written, you can debug your program with NINDY, an EPROM resident debug monitor. NINDY enables you to download code, set seven different trace modes, display and modify memory or registers, and disassemble problem code sequences.

Available separately from Intel are the ASM-960 (assembly language) and iC-960 (high-level language) products which provide you with the code development environment for the QT960 boards.

The starter kit comes in two versions: the QT960F version has fast SRAM, high speed EPROM and Flash memory; the QT960E version has lower cost SRAM, Flash memory and no high speed EPROM. Each version has NINDY in either EPROM (QT960F) or Flash memory (QT960E), power supply cable, and the QT960 User Manual. Both versions also include the parts list, source code of the debug monitor, and the board data base (schematics) all on diskette. Armed with this starter kit you now have a system to evaluate and prototype your product ideas quickly and at low cost.

November 1990
Order Number: 270743-002

FEATURES

QT960 FEATURES

- 20 MHz Execution Speed
- 128K Bytes to Zero Wait State EPROM‡
- 128K Bytes of Flash Memory
- 128K Bytes of Zero Wait State SRAM‡
- Programmable Wait State Generator
- Prototyping Wire Wrap Area
- Five Instruction Traces
- Two Hardware Breakpoints
- Display/Modify Memory and Registers
- Code Disassembly
- High Level Language Support
- RS-232 Communications Link
- The QT960E Version has 128K Bytes of Two Wait State SRAM and 128K Bytes Four Wait State Flash Memory

Product Order Codes: EVQT960F20 and EVQT960E20

†CHMOS IV is a patented Intel process.
‡QT960F Version only.

FAST AND EASY CODE UPDATES

128K Bytes of Intel's 28F256 Flash memory provides an easy and quick method of changing your code in nonvolatile memory. Flash memory may be conveniently reprogrammed without removing it from the board while software is under development.

FAST EPROM

Interleaved fast EPROM (Intel's 27C202) on the QT960F version yields one-zero-zero-zero wait state code access. It efficiently utilizes the four word burst capabilities of the 80960KB bus maximizing program performance.

PROTOTYPING SUPPORT

A prototyping wire wrap area is provided on board with access to the system's signals and buses. This area gives you access to the board's features and allows you to easily test design ideas. A system bus connector is also provided for off board prototyping.

PROGRAMMABLE WAIT STATE GENERATOR

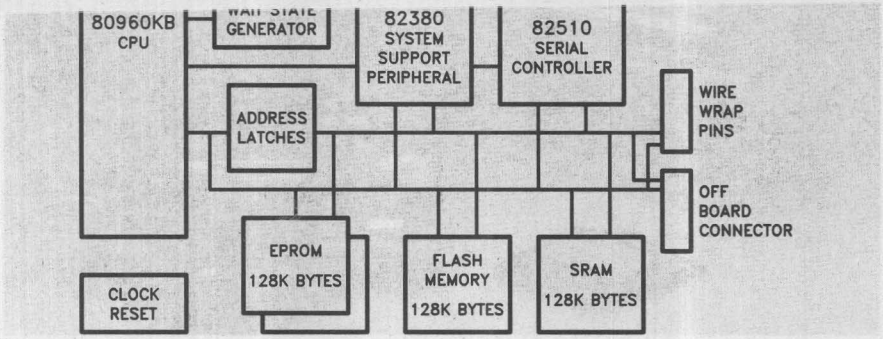
A software programmable wait state generator enables you to quickly model various memory speeds. Under software control you can set over 16 different wait state combinations and evaluate the performance of your target system.

DMA

The board offers you eight DMA channels accessed through a NINDY library function using Intel's 82380. In addition, off board connectors provide DMA I/O capabilities.

FIVE INSTRUCTION TRACES AND TWO HARDWARE BREAKPOINTS

NINDY utilizes the built-in trace capabilities of the 80960KB to provide you with single step, supervisor, call, return, and branch instruction tracing offering you extensive debug capabilities for software examination and modification. Two hardware breakpoints enable you to break on and examine EPROM resident code.



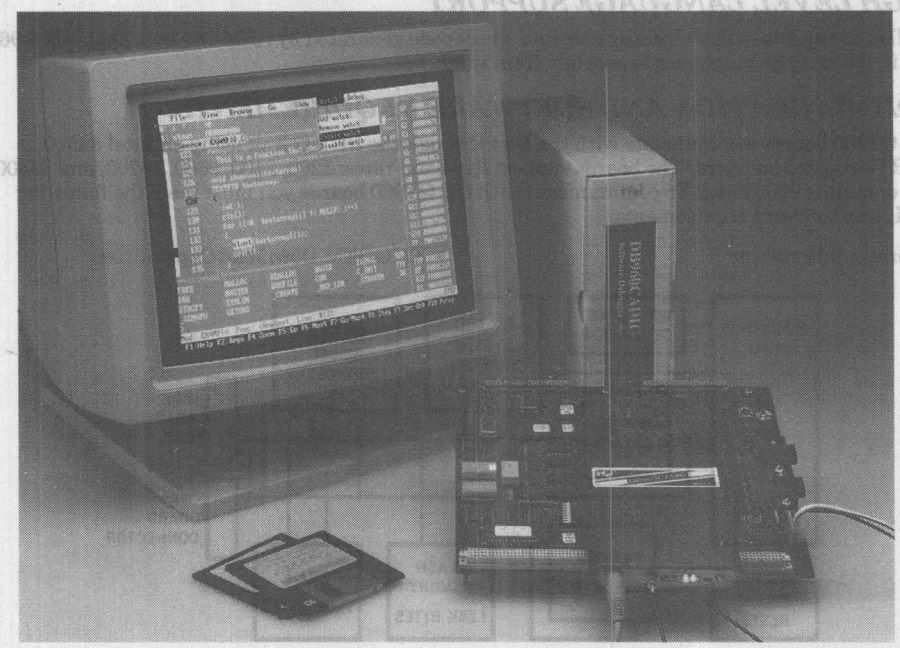
270743-2

Block Diagram of the QT960 Board

For information or the number of your nearest sales office call 800-548-4752 (U.S. and Canada).
Intel Corporaton, Literature Department, 3065 Bowers Avenue, Santa Clara CA 95051, United States. Tel: 408-987-8080.

8

DB960CADIC IN-CIRCUIT DEBUG MONITOR



280900-1

DB960CADIC

Intel's DB960CADIC, the in-circuit debug monitor for the 33 MHz 80960CA embedded microprocessor, represents a new generation of development tool technology.

DB960CADIC allows users to debug high-speed, cached applications at the full speed of the 80960CA target processor. Controlled by Intel's DB interface, DB960CADIC offers the user a tool with a powerful feature set at a fraction of the cost of traditional development tools. DB960CADIC is designed to improve productivity by allowing the user to debug software before and after the target system arrives, with minimal hardware intrusion.

December 1990
Order Number: 280900-001

FEATURES

- Real-time emulation of the 80960CA embedded microprocessor at speeds up to 33 MHz
- Full development and debug support for 80960CA on-chip cache and RAM
- Minimal intrusive operation, allowing the user to debug the target system with minimal modification subject to initial design constraints
- Breakpoint capabilities include ten software breakpoints, two hardware execution address breakpoints, and two hardware data address breakpoints. The human interface supplements these breakpoints with the ability to break on data values, conditions, and a four-state state machine in non-real time.
- Low-Cost
- Source-Level, Symbolic Debugging in a Windowed Human Interface with pull down Menus (DB). This interface is consistent across 80960CA tools.
- 128 KBytes User Memory
- Virtual I/O, the ability to perform I/O between the DB960CADIC unit and the host
- In-circuit operation facilitates easy transition between target systems
- Optional Stand-Alone Self-Test (DB960CASAST) Module
- Optional Logic Analyzer Interface Board (LAI960CA)

8

FEATURES

FULL-SPEED DEBUG AND DEVELOPMENT

The DB960CADIC In-circuit Debug Monitor provides sophisticated real-time hardware and software debug capabilities for 80960CA embedded microprocessor-based designs. The user can run at the full speed of the target processor, ensuring that elusive timing bugs will be found. The DB960CADIC is jumpered to receive a clock pulse from either the user's target system, or from an internal 25 MHz clock.

IDEAL FOR ALL STAGES OF DEVELOPMENT

DB960CADIC can be used by both hardware and software developers, at any stage of design. Early in the development process, DB960CADIC allows software debugging when inserted into an existing 80960CA board such as the DB960CASAST module or the EV80960CA board. Later in the design cycle, DB960CADIC can be inserted into the user's target system, thus facilitating debug of hardware/software integration.

SPEED DEVELOPMENT WITH SOURCE CODE, SYMBOLIC DEBUGGING

Using source code oriented debugging in a windowed, symbolic interface, software engineers can increase productivity by debugging in the medium they are familiar with, software source.

Commands can be entered via either function keys, pull-down menus which group logically related commands, or a supplementary command line which allows entry of complex conditions. In addition, source code symbolics can be used to examine and modify memory and registers. Optimal symbolic debugging can be achieved when using DB960CADIC with genuine Intel languages.

POWERFUL BREAK CAPABILITIES

DB960CADIC provides complex emulation control by utilizing the on-chip debug registers within the 80960CA. Real-time break capabilities include the ability to break on any two execution addresses or data access addresses in hardware. Software breakpoints are also used to supplement the hardware breakpoints for RAM-based memory subsystems. DB960CADIC extends these capabilities by providing the ability to break on data values, NOT data values, or combinations of the above in a four-state state machine. More complex conditions such as breaking when a variable is less than a certain value can be entered via a very flexible feature called conditional breakpoints.

128 KBYTES USER MEMORY

DB960CADIC provides the user with 128 Kbytes of memory in Region F of the 80960CA target space. Since the debug monitor is also placed in Region F, the on-chip bus interface unit of the 80960CA is configured to address region F as byte-wide memory with 5 waitstates and no burst accesses allowed.

VIRTUAL INPUT/OUTPUT

DB960CADIC is shipped with documented library calls which provide users with a built-in mechanism of performing target I/O using the host system. These libraries provide the ability to simulate I/O operations in the target system before target hardware is available.

HIGH SPEED SERIAL LINK

Communication between a host and the DB960CADIC module is supported via RS232 and RS422 communication links. RS232 allows access to industry standard serial protocols while the RS422 link provides a higher speed communication mechanism currently emerging in the development market. PC AT Compatible RS422 communication boards are available from various third party vendors.

FEATURES

OPTIONAL STAND-ALONE SELF-TEST CHASSIS

An optional stand-alone self-test chassis complements DB960CADIC by allowing the user to debug and test code before prototype hardware is available. The DB960CASAST includes self-test circuitry to ensure that the DB960CADIC unit is working correctly. It also provides 4 Megabyte of DRAM to be used for developing applications. This memory has a (3,1,1,1) waitstate pattern at 25 MHz. This waitstate pattern is programmable using the bus controller unit in the 80960CA. It also includes an 8254 programmable timer which can optionally interrupt the 80960CA processor and provide the ability to time code sequences.

OPTIONAL LOGIC ANALYZER INTERFACE BOARD

The LAI960CA board provides access to 80960CA pins by routing the signals to easily accessible stake pins while passing them through to the target system.

SOFTWARE COMPLETES THE SYSTEM

Intel provides a comprehensive software development environment to complement DB960CADIC. This environment includes C and ASM source languages, a retargetable debug monitor, and DB960CADIC. The languages support the entire range of 80960 embedded processors.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support, and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, "*iComments*" publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

8

SPECIFICATIONS AND REQUIREMENTS

HOST SYSTEM REQUIREMENTS

Host system requirements to run the in-circuit debugger include the following:

—DOS version 3.2 or later excluding DOS 4.0

—640 bytes of RAM in conventional memory

—A 20 MB hard disk

—An RS232 or RS422 Serial Port

Evaluated Systems include:

IBM PC AT* with DOS 3.3
COMPAQ 386* with DOS 3.3
Intel 30$^1/_3$02* with DOS 3.3
IBM Personal System/2* Model 70/80 with DOS 4.01

PHYSICAL CHARACTERISTICS

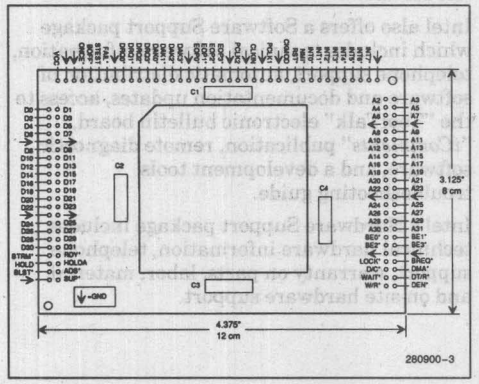


Figure 1. LAI960CA Pinout Diagram

ENVIRONMENT CHARACTERISTICS

Operating Temperature: + C to + C (50° to 104° F)

Operating Humidity: Maximum of 90% relative humidity, non-condensing.

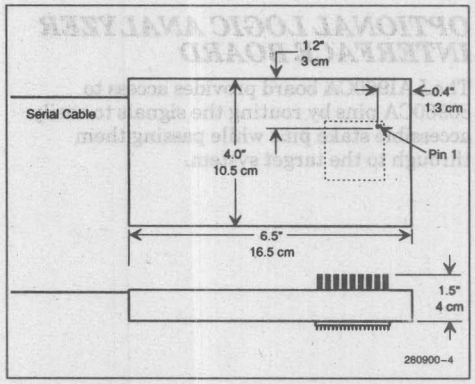


Figure 2. Debugger Hardware Physical Dimensions

SPECIFICATIONS AND REQUIREMENTS

DB960CADIC INTERFACE CONSIDERATIONS

Target systems intended to receive DB960CADIC must meet the following requirements:

- The target system must not respond to memory accesses in Region F (0F0000000-0FFFFFFFF) when DB960CADIC is installed. DB960CADIC provides an ACTIVE out signal which can be used to qualify bus logic to prevent this occurrence when DB960CADIC is installed.
- The Target System must provide 1.3 Amps of power (worst case) .9 Amps average to power the DB960CADIC unit.
- Use of one of the nine directly accessible 80960CA interrupts.
- Use of interrupt table entry 242 or 248.
- Additional Signal Loading as follows:

The DB960CADIC makes use of the PCLK outputs, D0 through D7, and some of the address and control signals of the processor. The following table lists the worst case loadings added by the presence of the DB960CADIC circuitry.

Signal Name	DC Load (microA.)	Capacitive Load (pF.)
PCLK1	+25/−250	8
PCLK2	+30/−255	17
CLKIN	+12/−12	13
D0:D7	+20/−600	10
A31:26	+25/−250	11
A2:A17	+20/−100	10
BE0*, BE1*	+20/−100	10
ADS*	+50/−500	13
W/R*	+50/−500	13
WAIT*	+25/−250	8
BLAST*	+25/−250	8
FAIL*	+20/−20	8
RESET*	+15/−15	25
INT0:7*	+20/−500	15
NMI*	+20/−500	15

Additional Loading Imposed on the Target by the DB960CADIC

ORDERING INFORMATION

DB960CADIC	In-circuit debug monitor for the 80960CA embedded microprocessor. Operates at speeds up to 33 MHz. Includes hardware debug module, RS232/RS422 serial cables, DOS host software, and documentation.
DB960CASAST	Stand-Alone Self-Test Unit for DB960CADIC. Includes built-in power supply, self-test board, 4 MByte of usable DRAM for code development, and enclosure.
DB960CAST	DB960CADIC and DB960CASAST as described above.
LAI960CA	Optional Logic Analyzer Interface Board for the 80960CA system. Does not require DB960CADIC.

For more information or the number of your nearest Intel sales office, call 800-548-4725 (good in the U.S. and Canada).

UNITED STATES, Intel Corporation
3065 Bowers Ave., Santa Clara, CA 95052-8126
Tel: (408) 765-8080

JAPAN, Intel Japan K.K
5-6 Tokodai, Tsukuba-shi,
Ibaraki-Ken, 300-26
Tel: 029747-8511

UNITED KINGDOM,
Intel Corporation (U.K.) Ltd.
Pipers Way, Swindon,
Wiltshire, England SN3 1RJ
Tel: (44) (0793) 696000

SIM960CA PERFORMANCE SIMULATOR

```
                PERFORMANCE STATISTICS
Number of instructions executed: 12022
Number of cycles: 6068
Total simulated time: 183.88 (micro seconds)
Speed: 65.38 MIPS (0.50 cycles per instruction)
Number of stack frames cached on chip: 8
Stack cache overflows: 0
Number of alignment errors: 0 (timing may be incorrect if > 0)  Warn: Yes
Cycles per second: 33000000
Bus utilization: 66 %
Waits: NRADWT=0 NRDDWT=0 NXDAWT=0 NWADWT=0 NWDDWT=0

                      Hits    Misses  Efficiency
Branch prediction:    1000         1     99.90 %

                                From Cache      From memory     Efficiency
Instruction words fetched:           15013               36        99.76 %

Instruction usage       Number  Percentage
Loads:                    1001        8.33
Stores:                   1001        8.33
Calls:                       1        0.01
Branches:                 1002        8.33

C>
```

280862-1

SOFTWARE DEVELOPMENT TOOL FOR BENCHMARKING AND DEBUGGING 80960CA MICROPROCESSOR-BASED CODE

SIM960CA is a software simulator that emulates the instruction set of the 80960CA microprocessor. Designers can use SIM960CA to benchmark application performance and to develop and debug early 80960CA designs before 80960CA target systems are available. Existing language tools such as iC960 and ASM960 can be used to develop 80960CA applications, minimizing time to market.

FEATURES

- Simulates 80960CA microprocessor
- Summarizes performance statistics, such as
  - — execution speed (rated in MIPS)
  - — number of cycles per instruction
  - — Profile of instructions executed
    - — loads, stores, calls and branches
  - — bus utilization
  - — 80960CA execution time between any two locations
  - — branch prediction efficiency
- Display/Modification of memory and register contents
- Instruction disassembly
- Trace/break on instruction execution, address reads and writes
- Timing accuracy to + or − 5% ensuring accurate performance benchmarks
- Accepts iC960 or ASM960 COFF executable files and binary files as input
- Provides execution control—breakpoints and single stepping
- User-selectable clock, number of wait states

8

October 1990
Order Number: 280862-003

FEATURES

80960CA ARCHITECTURE SIMULATION

The SIM960CA Performance Simulator emulates the instruction set of the 80960CA microprocessor, allowing the user to specify wait states and clock speed for their target system. 80960CA applications can be developed and debugged before 80960CA target systems are available. Source code can be compiled using the 80960KX series C Compiler (iC960), Assembler (ASM960) and the resulting COFF executable file loaded into the 80960CA Performance Simulator for subsequent execution.

Using SIM960CA's trace capability, instruction execution, read and write activity at a particular location can be traced. Timing profiles of 80960CA operations are accurate to within plus or minus 5%. Estimates of actual 80960CA code performance can thus be made without an 80960CA-based target.

SIM960CA supports 80960-based C code such as standard procedures in LIBC, including STDIO routines such as PRINTF, MALLOC and MEMCPY.

PERFORMANCE STATISTICS

The SIM960CA Performance Simulator is used primarily to benchmark 80960CA performance gathering a wealth of statistics during 80960CA code execution. Some statistics that are gathered include:

- speed in MIPS (millions of instructions/sec.)
- number of cycles per instruction
- profile of instructions executed
- instructions fetched from memory
- number of instructions executed
- branch prediction efficiency
- total simulated 80960CA execution time (millionths of seconds)
- stack cache overflows
- instructions received from cache
- number of 80960CA clock cycles used
- bus utilization
- current clock speed (cycles/sec)
- wait state information

Performance statistics being gathered can be reset at any point, allowing performance analysis between any two locations. For example, execution time for a particular procedure can be measured. All timings, of course, are a function of the specified clock speed and number of wait states, selected by the user.

COMPLETE EXECUTION CONTROL

SIM960CA allows complete simulation control including control over where to begin or end the execution, number of instructions or clock cycles to execute, single stepping and the capability to execute an operating system command.

MULTIPLE DEBUG OPERATIONS

A variety of debug operations are available with SIM960CA. Users can trace instruction execution flow in a verbose or brief format. The brief format prints the address and instruction for each operation. Verbose format also prints out the cache, bus and instruction pipeline activity. 93 break or trace points can be set and deleted on instruction execution and memory read/writes. Instructions can be disassembled. Memory can be modifed or displayed in 32 bit hexadecimal, ASCII, octal or control character format. The user can flush the contents of the register cache for examination or fill memory with a specified value.

Users can also write a section of memory to a file and later read the contents of that binary file into memory.

HOST REQUIREMENTS

- IBM PC, XT or AT with 512KB of conventional memory Intel Aboveboard with 2MB RAM is required for iC960 C Compiler)
- At least one 5¼" Floppy Disk drive (360KB capacity)
- DOS Operating System (version 3.3)

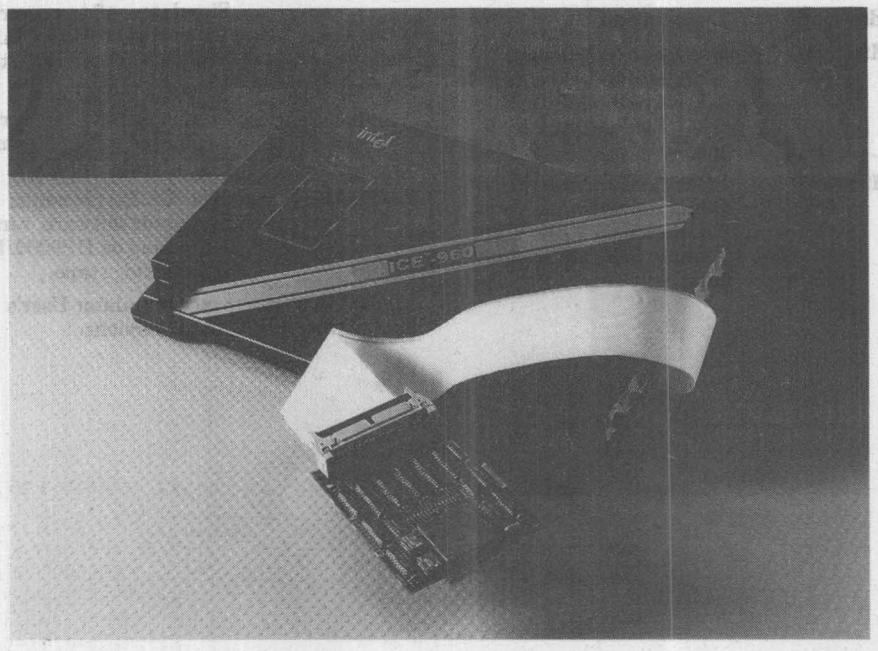
ORDERING INFORMATION

ORDERING INFORMATION

Order Code	Description
SIM960CAD	80960CA Performance Simulator software, version 1.1, hosted on MS-DOS, 5.25″ flexible diskette media.
SIM960CAV	80960CA Performance Simulator software, version 1.1, hosted on VAX/VMS, 4-track, 1600 BPI magnetic tape.
SIM960CAM	80960CA Performance Simulator software, version 1.1, hosted on MicroVAX/ VMS, TK-50 cartridge tape.
SIM960CAU	80960CA Performance Simulator software, version 1.1, hosted on Sun 3/Sun OS, cartridge tape.
SIM960CAH	80960CA Performance Simulator software, version 1.1, hosted on HP9000/HP-UX cartridge tape.

SIM960CA Performance Simulator User's Manual included with all versions.

80960SA/SB DEVELOPMENT SUPPORT



280906-1

COMPREHENSIVE DEVELOPMENT SUPPORT FOR 80960SA/SB EMBEDDED APPLICATIONS

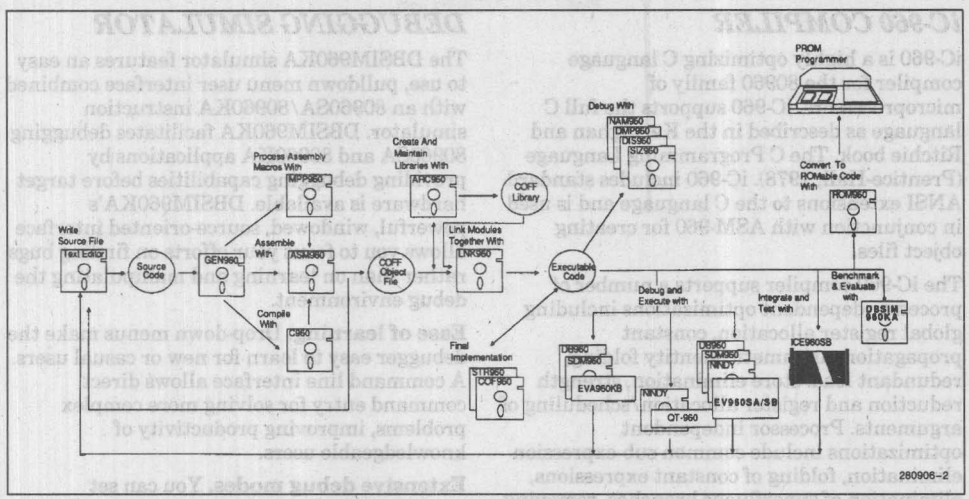
Intel provides comprehensive development support for the 80960 component architecture, including the newest members, the 80960SA and 80960SB. Tools range from compilers to simulators and from debuggers to emulators. All designed specifically for members of the 80960 family, allowing you to take full advantage of their RISC-based design while reducing time to market.

DEVELOPMENT TOOLS AVAILABLE:

- ASM-960 macro assembler for developing and tuning speed-critical code
- iC-960 highly optimizing C language compiler for high-level language software development
- GEN-960 system generator for initializing your design to take advantage of 80960 on-chip features
- DB/SIM960KA debug simulator for 80960KA and 80960SA applications
- Windowed, interactive, source-level DB-960 debugger which can be targeted to one of the evaluation and development boards below, or customized to your target system
- Evaluation and development boards including the EV960SB, the QT80960KB, and the EVA960KB
- ICE-960SA/SB offers a full featured in-circuit emulator for the 80960SA/SB components

November 1990
Order Number: 280906-001

80960SA/SB DEVELOPMENT SUPPORT



ASM-960 MACRO ASSEMBLER

The ASM-960 macro assembler is used to fine-tune sections of code for peak program execution speed on the 80960SA, 80960SB, 80960KA, 80960KB, 80960MC, and 80960CA. ASM-960 does this by giving you absolute control over program instructions. In addition to the assembler and macro preprocessor, ASM-960 includes several utilities for application program maintenance and debug:

- LINKER provides incremental program linking/locating and link-time optimization.
- ARCHIVER allows you to build reusable function libraries for applications.
- DISASSEMBLER produces assembly language from object files.
- SYMBOL DUMPER provides symbolic information from a program file for facilitating low-level debug.
- ROM IMAGE BUILDER produces a hex file suitable for PROM programmers.
- Macro preprocessor provides code generation flexibility and improves code readability, reducing maintenance costs.

A Floating Point Arithmetic Library (FPAL) is included for the 80960SA, 80960KA, and 80960CA components. It eliminates the need to develop your own floating point code.

GEN-960 SYSTEM GENERATOR

The 80960 System Generator (GEN-960) helps you set up data structures for standalone, embedded applications that use the on-chip features of the 80960 architecture. GEN-960 is used with other 80960 tools to generate and refine ROM or RAM code. GEN-960 supplies a set of command and template files containing assembly code and linker control commands to set up processor control blocks, inter-agent communication mechanisms, system procedure tables, and other requirements for initialization. The result is a batch file containing all the commands needed to compile, assemble and link the final target system.

- Improves engineering productivity by automating the compilation, assembly and linking process
- Supplies sample initialization code, reducing programming time
- Save engineering time by simplifying the task of initializing each processor for on-chip capabilities

8

80960SA/SB DEVELOPMENT SUPPORT

iC-960 COMPILER

iC-960 is a highly optimizing C language compiler for the 80960 family of microprocessors. iC-960 supports the full C language as described in the Kernighan and Ritchie book, The C Programming Language (Prentice-Hall, 1978). iC-960 includes standard ANSI extensions to the C language and is used in conjunction with ASM-960 for creating object files.

The iC-960 compiler supports a number of processor dependent optimizations including global register allocation, constant propagation, arithmetic identity folding, redundant load/store elimination, strength reduction and register allocation/scheduling of arguments. Processor independent optimizations include common sub-expression elimination, folding of constant expressions, elimination of superfluous branches, removing unreachable code, tail recursion and procedure incorporation.

iC-960 includes a standard C library with I/O functions and mathematical routines. A second library provides low level, environment-dependent routines emulating UNIX* system calls and supplies I/O routines for the EVA-960 Software Execution Vehicle.

iC-960 also includes the following enhancements for embedded application development:

Programs may be easily placed in ROM.
Memory-mapped I/O allows high-level language access to application-specific input and output.
In-line assembly simplifies the integration of C language and assembly code for speed-critical functions.

Floating point support produces in-line code to take full advantage of the floating point capability of the 80960SB, 80960KB and 80960MC.

Symbolic debugging of source code for iC-960 and ASM-960 is provided by the DB-960 Source Level Debugger, the DBSIM960KA debugging simulator, the DB960CADIC in-target debugger, and the ICE960SB and ICE960KB emulators.

DEBUGGING SIMULATOR

The DBSIM960KA simulator features an easy to use, pulldown menu user interface combined with an 80960SA/80960KA instruction simulator. DBSIM960KA facilitates debugging 80960SA and 80960KA applications by providing debugging capabilities before target hardware is available. DBSIM960KA's powerful, windowed, source-oriented interface allows you to focus your efforts on finding bugs rather than on learning and manipulating the debug environment.

Ease of learning. Drop-down menus make the debugger easy to learn for new or casual users. A command line interface allows direct command entry for solving more complex problems, improving productivity of knowledgeable users.

Extensive debug modes. You can set conditional breakpoints, pass points, and temporary breakpoints as needed.

See into your program. Using pull-down menus or function keys, you can browse source and Call stacks, monitor processor registers, view screen output, and watch the values of variables change.

Full debug symbolics for maximum productivity. You need not know whether a variable is an unsigned integer, a real, or a structure: the debugger displays program variables in their respective type formats.

80960SA/SB DEVELOPMENT SUPPORT

EVA-960KB4MB SOFTWARE EXECUTION VEHICLE

The EVA-960KB4MB is a software execution vehicle for the 80960KA/KB microprocessor. It is a single PC AT plug-in board which provides easy and convenient architecture evaluation and benchmarking, as well as software development. Since the board uses an 80960KB, 80960SA and 80960SB performance can be extrapolated. The EVA-960KB4MB contains the following:

- 4 MB or 16 MB (EVA960KB16MB) of one wait-state program memory (DRAM)
- 64 Kbytes of zero wait-state program memory (SRAM)
- Three-channel programmable interval timer
- Hosted debug monitor which supports two hardware and 64 software breakpoints, single-step program execution, register and memory access, program download and upload
- DOS access libraries that allow: screen display, keyboard input, read and write disk files, and the ability to spawn a DOS process that could communicate with serial or parallel I/O
- 20 MHz operation, allowing software to operate at full speed of 80960KB

EVA-960KB4MB also operates with the DB-960 Source Level Debugger for code development/debug prior to target system availability.

SOURCE-LEVEL DEBUGGER

The DB-960 Debugger with source-level debug capabilities is available for PC ATs equipped with DOS. DB-960 can debug 80960 code executing on an Intel EVA-960 Software Execution Vehicle or on a hardware target system via a serial interface. The EVA-960 targeted debugger uses I/O resources provided by the PC, while 80960 code executes at high speed on the EVA-960. Two serial versions of DB-960 are available. DB-960CADIC plugs directly into the 80960CA socket on your prototype, offering a "plug-in and go" debug environment. DB-960D is a serial, retargetable version of DB-960 whose system debug monitor can be customized for 80960SA/SB, 80960KA/KB, or 80960CA operation.

Ease of learning. Drop-down menus make the debugger easy to learn for new or casual users. A command line interface allows direct command entry for solving more complex problems, improving productivity of knowledgeable users.

Extensive debug modes. You can set conditional breakpoints, pass points, and temporary breakpoints as needed.

See into your program. Using pull-down menus or function keys, you can browse source and Call stacks, monitor processor registers, view screen output, and watch the values of variables change.

Full debug symbolics for maximum productivity. You need not know whether a variable is an unsigned integer, a real, or a structure: the debugger displays program variables in their respective type formats.

In-Target Debug. Porting the DB960D retargetable monitor to your target system allows the debugger to be used in-target, thus facilitating debugging of code dependent upon hardware interaction.

80960SA/SB DEVELOPMENT SUPPORT

ICE960SB IN-CIRCUIT EMULATOR

ICE960SB is a full featured in-circuit emulator for the 80960SA and 80960SB components. A separate ICE probe can be purchased to support 80960KA and 80960KB components. ICE960SB includes:

Full speed emulation of the 80960SA/SB components to 16 MHz

- Complete symbolic information when used with Intel 80960 compilers
- 1024 Frames Bus or Execution Trace with Time-Tags
- Comprehensive break capabilities including execution addresses, instruction type, bus read/write/access, data values, and external synch lines
- Qualification of break conditions based on a 8-state machine or an occurrence counter
- Fastbreaks to dynamically access memory or variables during emulation
- Examine and modify memory and 80960 registers
- Stand-Alone Self-Test module provides diagnostic circuitry and 256 Kbytes of memory for software development
- Optional 2 Mbyte of relocatable expansion memory
- Support for socketed and surface mounted 84 Pin PLCC components and surface mounted 80 Pin EIAJ components via ONCE mode
- DOS Hosting with support for RS232 and RS422 communication links

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support, and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, "*iComments*" publication, remote diagnostic software, and a development tools troubleshooting guide.

Intel's Hardware Support package includes technical hardware information, telephone support, warranty on parts, labor, material, and on-site hardware support.

	applications; contains standard STDIO libraries and in-line assembly capability.
GEN960	80960 System Generation software automates the compilation, assembly and linking process. Simplifies usage of 80960 sophisticated features.
DBSIM960KA	Debugging Simulator software emulates the 80960SA and 80960KA instruction set allowing code development and debugging prior to hardware prototype availability.
DB960KBDEVA	Source Level Debugger software for the 80960KB/KA with powerful debug capabilities including conditional breakpoints, source and Call stack browsing, memory/register display and modification, and ability to watch variables change value. Requires EVA-960KB4MB Software Execution Vehicle. For PC AT hosted systems only.
	80960KA/KB components. Includes 4 Mbyte of on-board memory, system debug monitor and code download software. Code compatible with the 80960SA/SB components. Required by DB960KBDEVA.
EVA960KB16MB	Identical to EVA960KB4MB with 16 Mbyte of DRAM instead of 4 Mbyte.
ICE960SB	In-Circuit emulator for the 80960SA/SB components. Includes ICE base and probe, stand-alone self-test module, and your choice of PLCC or PQFP target adapters. Optional 2 Mbyte relocatable expansion memory option provides overlayable memory for software prototyping and hardware debugging.

80960SA/SB DEVELOPMENT SUPPORT

ARCHITECTURE EVALUATION STARTER KITS

960SKit3 Contains ASM960D Assembler and iC960D Compiler

DB960KIT2 Kit contains DB-960KBDEVA (KB version of DB-960 used with EVA-960), EVA960KB4MB Software Execution Vehicle, ASM960D and C960E. Requires PC AT with 640K memory.

DB960KIT3 Kit contains DB-960D (serial version of DB-960 supporting the 80960SA/SB, 80960KA/KB and 80960CA components (operating on PC-AT/DOS), ASM960D and C960D. Requires PC AT with 640K memory.

Product Code to order, by Host

Product Category	PC-AT/DOS	UNIX-386 V.4	OS/2	Sun 3/ UNIX	HP9000/ HP-UX	VAX/ ULTRIX	μVAX/ ULTRIX
Assembler	ASM960D	ASM960S	ASM960P	ASM960U	ASM960H	ASM960VX	ASM960MX
C Compiler	C960D	C960S	C960P	C960U	CP60H	C960VX	C960VX
System Gen	GEN960D	—	—	GEN960U	GEN960H	—	—
SX Debugger	DB960D	—	—	—	—	—	—
KX Debugger	DB960KBDEVA	—	—	—	—	—	—
	DB960D	—	—	—	—	—	—
CA Debugger	DB960CADIC	—	—	—	—	—	—
	DB960D	—	—	—	—	—	—
SA Simulator	—	DBSIM960KAS	—	—	—	—	—
CA Simulator	SIM960CAD	—	—	SIM960CAU	SIM960CAH	—	—
ICE960SB	ICE960SB	—	—	—	—	—	—
ICE960KB	ICE960KB	—	—	—	—	—	—

8

iRMK™ 960 REAL-TIME KERNEL

- **32-bit real-time multi-tasking kernel for the i960™ microprocessor family**
- **Flexible, modular design to ease system integration**
- **Fast execution with predictable response time for time-critical applications**
- **Compact code size (14Kbytes-including all optional modules)**
- **Requires only an i960 KA, KB, or MC embedded processor**
- **Bus Independent**
- **Easy customization and add-on enhancements**
- **Easily EPROMmable**
- **Comprehensive development tool support**

THE 32-BIT REAL-TIME KERNEL OF CHOICE FOR THE i960™ MICROPROCESSOR

The iRMK™ 960 Real-Time Kernel is the 32-bit real-time executive developed and supported by Intel, the i960™ architecture experts. The kernel is a small, fast and highly modular package of system control software. It contains the basic software building blocks that act as the foundation in using the key features of the i960 microprocessor. The iRMK 960 software is fully supported by an array of tools that work in the most popular development environments (i.e. DOS, VAX/VMS*, SUN**).

The iRMK 960 Real-Time Kernel is available off-the-shelf. The kernel reduces the cost and risk of designing and maintaining software for numerous real-time applications such as, embedded control systems and dedicated real-time subsystems in multiprocessor environment. Use of the kernel can save man years that might otherwise be spent developing or porting another real-time kernel. This means reduced time to market for the user.

Intel Corporation assumes no responsibility for the use of any circuitry other than circuitry embodied in an Intel product. No other circuit patent licenses are implied. Information contained herein supersedes previously published specifications on these devices from Intel.
©Intel Corporation, 1989

June 1989
Order Number: 281006-001

ARCHITECTURAL OVERVIEW

At the heart of the architecture are the kernel core modules consisting of a scheduler, task manager, interrupt manager, and time manager (See Figure 1). As additional building blocks, the kernel provides optional modules consisting of a mailbox manager, semaphore manager, memory manager, on-processor interrupt controller manager, and fault handler manager. The optional device manager for the 82380 Integrated System Peripheral (ISP) and 8254 Programmable Interval Timer (PIT) complete the architecture.

FUNCTIONAL FEATURES

A Full Set Of Real-Time Building Blocks

The kernel provides a full set of services for real-time applications including task management, time management, synchronization of and communications between tasks, and memory pool management.

Task Management:

The iRMK 960 kernel uses system calls to create, manage, and schedule tasks in a multi-tasking environment. It provides pre-emptive priority scheduling combined with optional time-slice (round robin) scheduling.

The scheduling algorithm used by the kernel enables tasks to be rescheduled in a fixed amount of time regardless of the number of tasks. Applications may contain any number of tasks.

An application can integrate optional task handlers to customize task management. These handlers can execute on task creation, task switch, task deletion, and task priority change. Task handlers can be used for a wide range of functions, including saving and restoring the state of coprocessor registers on task switch, masking interrupts based on task priority, or implementing statistical and diagnostic monitors.

Interrupt Management:

iRMK 960 interrupts are managed by immediately switching control to user-written interrupt handlers when an interrupt occurs.

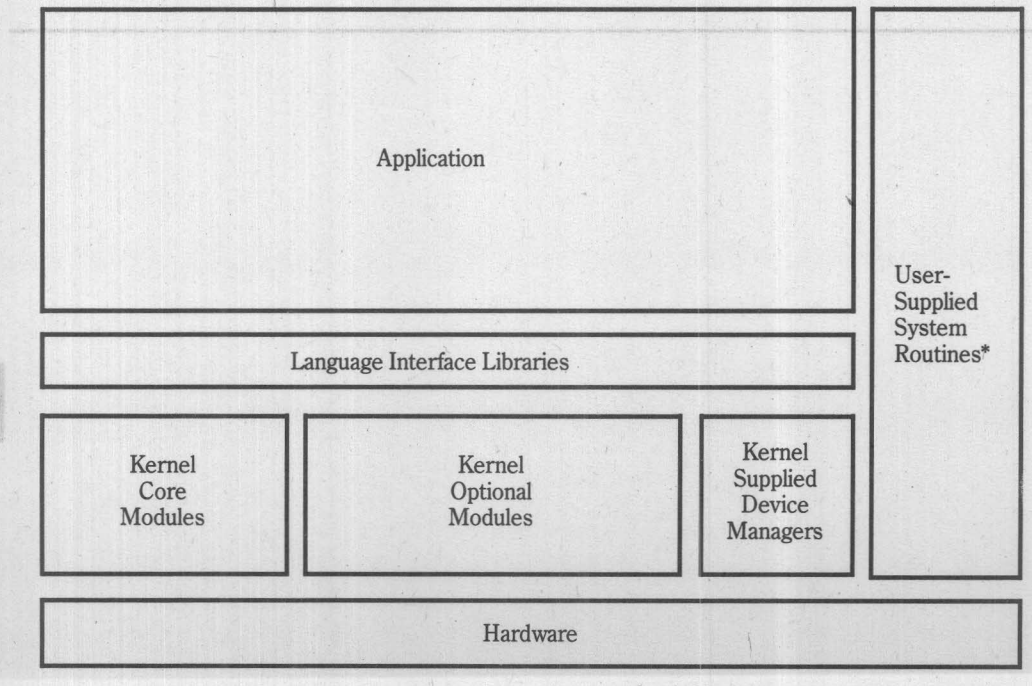


Figure 1: iRMK™ 960. Real-Time Kernel Architecture

Response to interrupts is both fast and predictable. Most of the kernel's system calls can be executed directly from interrupt handlers.

Time Management:

The time management features included in the kernel provide single-shot alarms, repetitive alarms, and a real-time clock. In addition, alarms can be reset.

These time management facilities can solve a wide range of real-time programming problems. Single-shot alarms, for example, can be used to handle timeouts. If the timeout occurs, the alarm invokes a user-written handler; if the event occurs before the timeout, the application simply deletes the alarm. Other uses for the kernel's time management facilities include polling devices with repetitive alarms, putting tasks to sleep for specified periods of time, or implementing a time-of-day clock.

Intertask Synchronization And Communication:

Semaphores, regions, and mailboxes are the key mechanisms the kernel uses for synchronizing tasks and communicating between tasks.

Semaphores are objects used for intertask signaling and synchronization. Tasks exchange abstract "units" with semaphores as a means of becoming synchronized. A task requests a unit from a semaphore to gain access to a resource. If the resource is available, the semaphore will have a unit to give to the task, enabling the task to proceed. A task sends a unit to a semaphore to indicate that it has released a previously obtained resource.

A special binary type of semaphore is called a Region. Regions are used to ensure mutual exclusion, thus preventing deadlock when tasks contend for control of system resources. A task holding a region's unit runs at the priority of the highest priority task waiting in queue for the region's unit.

Mailboxes are queues that can hold any number of messages and are used to exchange data between tasks. Either data or pointers can be sent using mailboxes. The kernel allows mailbox messages to be of any length. High priority messages can be placed (jammed) at the front of the message queue to ensure that they are received and processed before other messages queued at the mailbox.

To ensure that high priority tasks are not blocked by lower priority tasks, the kernel allows tasks to queue at semaphores and mailboxes in priority order. The kernel also supports first-in, first-out task queueing.

Memory Pool Management:

The iRMK 960 kernel uses the concept of memory pools to efficiently divide and manage blocks of memory. The memory pool manager provides for both fixed and variable block allocation.

Memory can be divided into any number of pools. Multiple memory pools might be created for different speed memories, or for allocating different size blocks. The times to allocate and de-allocate fixed-size areas from within a pool have a fixed upper bound.

The kernel-supplied memory manager works with flat memory architecture. Users can also write their own memory manager to provide different memory management policies or support virtual memory.

Hardware Requirements And Support

The kernel requires only an i960 microprocessor and sufficient memory for itself and its application. The kernel's design, however, recognizes that many systems use additional programmable peripheral devices and coprocessors. The kernel provides optional device managers for:

- The 82380 Integrated System Peripheral (ISP) chip
- The 8254 Programmable Interval Timer (PIT) chip

An application can supply managers for other devices and coprocessors in addition to or in replacement of the devices listed above.

The openness of the iRMK 960 kernel is a major benefit to the OEM. The kernel is designed to be programmed into PROM or EPROM, making it easy to use in embedded designs. In addition, it can be used with any system bus, including those of MULTIBUS I and MULTIBUS II bus architectures.

A Modular Architecture For Easy Customization

The kernel is designed for maximum flexibility. It can be customized for any application. Each major function, mailboxes for example, is implemented as a separate module. The kernel's modules have not been linked together and are supplied individually. (See Table 1 for the list of kernel modules, and their approximate sizes.)

The user links only the modules needed for his application. Any module not used does not need to be linked in, and does not increase the size of the kernel in your application. The user can also replace any optional kernel module with one that implements specific features required by the application. For example, the user might want to replace the kernel's memory manager with one that supports virtual memory.

Table 1: iRMK™ 960 Kernel Modules And Approximate Sizes

Core Modules	Bytes
Task Manager	2600
Interrupt Manager	150
Time Manager	3000
Scheduler	1700
Initialization	50
Optional Modules	
Mailbox Manager	1250
Semaphore Manager	2900
Memory Manager	1260
Fault Handler Manager	50
Miscellaneous	300
Optional Device Manager	
82380 Integrated System Peripheral	4200
8254 Programmable Interval Timer	1200

Total size of the (entire) kernel (minus device managers) is about 13.5KBytes.

Developing With The iRMK™ 960 Real-Time Kernel

Kernel applications can be written using any language or compiler that produces code that executes on the i960 microprocessor. This independence is achieved by using an interface library. This library works with the idiosyncracies of a particular language — for example, the ordering of parameters. The interface library translates the calls provided by the language into a standard format expected by the kernel. Intel provides an interface library for our iC 960 compiler. The source code for this library is included, so that the user can modify it to support other compilers.

Because the kernel is supplied as unlinked object modules, applications can be developed on any system that hosts the development tools needed.

Comprehensive Development Tool Support

Intel provides a complete line of 80960 development tools for writing and debugging iRMK 960 applications. These tools include:

Software:	ASM 960 assembler iC 960 compiler	
	Note:	These tools are available for DOS, VAX/VMS*, MicroVAX*, SUN*, and EVA960KB4MB environment
Debuggers:	ICE™ 960	In-Circuit Emulator for the i960 microprocessor
	SMD™ 960	System Debug Monitor for the i960 microprocessor
Evaluation Vehicles	EVA960KB	AT Bus-Compatible Board
	A960KB4MB	AT Bus-Compatible Board with 4 MBytes of Memory
	QT960	Standalone Evaluation Vehicle

Intel Support, Consulting, And Training

With iRMK 960 kernel software, the developer has available the total Intel960™ architecture and real-time expertise of Intel's support engineers. Intel provides telephone support, on or off-site consulting, troubleshooting guides, and updates. The kernel includes 90 days of Intel's Technical Information Phone Service (TIPS). Extended support and consulting are also available.

Contents Of The iRMK™ 960 Kernel Development Package

The iRMK 960 Kernel comes in a comprehensive package including:

- Kernel object modules
- Source for the kernel supplied 82380 Integrated System Peripheral and 8254 PIT device managers
- Source for the iC 960 interface library
- Source for sample applications showing the following:
  - — Structure of kernel applications
  - — Use of the kernel with an application written in iC 960 language
  - — Compile, bind, and build sequences
  - — Sample initialization code for the i960 microprocessor
  - — Applications written to execute in a flat memory space
- User reference guide
- 90 days of customer support

LICENSING

iRMK 960 software requires prior execution of the standard Intel Software License Agreement (SLA). A single development copy requires a Class I license and allows iRMK 960 software to be loaded and run on one single-processor system.

SPECIFICATIONS

System Calls

The following items are system calls arranged by type:

iRMK 960 KERNEL SYSTEM CALLS LISTING

KERNEL INITIALIZATION

KN__initialize	Initialize kernel

OBJECT MANAGEMENT

KN__token__to__ptr	Returns a pointer to the area holding object
KN__current__task	Returns a pointer for the current task

TASK MANAGEMENT

KN__create__task	Creates a task
KN__delete__task	Deletes a task
KN__suspend__task	Suspends a task
KN__resume__task	Resumes a task
KN__set__priority	Change priority of a task
KN__get__priority	Return priority of a task

INTERRUPT MANAGEMENT

KN__set__interrupt	Specify interrupt handler
KN__stop__scheduling	Suspend task switching
KN__start__scheduling	Resume task switching

TIME MANAGEMENT

KN__sleep	Put calling task to sleep
KN__create__alarm	Create and start virtual alarm clock
KN__reset__alarm	Reset an existing alarm
KN__delete__alarm	Delete alarm
KN__get__time	Get time
KN__set__time	Set time
KN__tick	Notify kernel that clock tick has occurred

INTERTASK COMMUNICATION AND SYNCHRONIZATION

KN__create__semaphore	Create a semaphore
KN__delete__semaphore	Delete a semaphore
KN__send__unit	Add a unit to a semphore
KN__receive__unit	Receive a unit from a semaphore
KN__create__mailbox	Create a mailbox
KN__delete__mailbox	Delete a mailbox
KN__send__data	Send data to a mailbox
KN__send__priority__data	Place (jam) priority message at head of message queue
KN__receive__data	Request a message from a mailbox

MEMORY MANAGEMENT

KN__create__pool	Create a memory pool
KN__delete__pool	Delete a memory pool
KN__create__area	Create a memory area from a pool
KN__delete__area	Return a memory area to a memory pool
KN__get__pool__attributes	Get a memory pool's attributes

PROGRAMMABLE INTERRUPT CONTROLLER MANAGEMENT

KN__initialize__PICs	Initialize the PIC's
KN__mask__slot	Mask out interrupts on a specified slot
KN__unmask__slot	Unmask interrupts on a specified slot
KN__send__EOI	Signal the PIC that the interrupt on a specified slot has been serviced
KN__new__masks	Change interrupt masks
KN__get__slot	Return the most important active interrupt slot
KN__get__interrupt	Get address of specified interrupt handler

PROGRAMMABLE INTERVAL CONTROLLER MANAGEMENT

KN__initialize__PIT	Initialize the PIT
KN__start__PIT	Start PIT counting
KN__get__PIT__interval	Return PIT interval

PROCESSOR RECOGNIZED FAULT HANDLING

KN__get__fault__handler	Get address of fault handler currently associated with specified fault type
KN__set__fault__handler	Establish address of fault handler for the specified fault type

PROCESSOR INTERRUPT CONTROLLER SUPPORT

KN__get__processor__ __priority	Returns value of the processor
KN__set__processor__ __priority	Change the value of the processor priority

8

Performance

The figures listed below were derived from a test suite running on a EVA-960 evaluation vehicle using an 80960KB running at 20 MHz. The EVA-960 has what is known as 2-1-1-1 wait-state memory; what this means is that the first instruction of a four instruction fetch takes two wait states, and each of the three successive instructions takes one wait state. The figures are the worst case values obtained from several set of test runs. The code was generated using the iC 960 DOS hosted compiler, Version 1.1

ACTION	TIME (in usec)
Create Pool	18
Get Pool Attributes	36
Delete Pool	1
Create Area	35
Delete Area	32
Create Semaphore	6
Delete Semaphore	14
FIFO Semaphore Send Unit	7
FIFO Semaphore Receive Unit	7
Region Semaphore Send Unit	18
Region Semaphore Receive Unit	14
Create Mailbox	19
Delete Mailbox	23
Send Data	21
Receive Data	21
Create Alarm	29
Delete Alarm	30
FIFO Semaphore Send/Receive Unit w/Task Switch	75
Suspend Task w Task Switch	70
Basic Task Switch	50
Create Task	62
Suspend Task	26
Resume Task	50
Delete Task	50
Get Priority	5
Set Priority	27
Set Interrupt	3
Get Interrupt	3

MANUALS

iRMK 960 User's Manual (Intel Order #463863-001).

TRAINING INFORMATION

Intel Customer Service Training

"80960 KA/KB Embedded Processor Training *Course*"

ORDERING INFORMATION

Order Code	Product Description
RMK960	iRMK 960 Real-Time Kernel

376™ Embedded Processor & Peripherals Data Sheets

9

376™ Embedded Processor & Peripherals Data Sheets

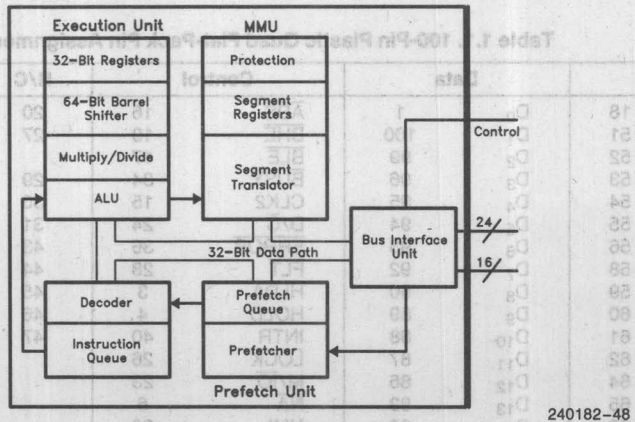
9

376™ HIGH PERFORMANCE 32-BIT EMBEDDED PROCESSOR

- **Full 32-Bit Internal Architecture**
  - **— 8-, 16-, 32-Bit Data Types**
  - **— 8 General Purpose 32-Bit Registers**
  - **— Extensive 32-Bit Instruction Set**
- **High Performance 16-Bit Data Bus**
  - **— 16 or 20 MHz CPU Clock**
  - **— Two-Clock Bus Cycles**
  - **— 16 Mbytes/Sec Bus Bandwidth**
- **16 Mbyte Physical Memory Size**
- **High Speed Numerics Support with the 80387SX**
- **Low System Cost with the 82370 Integrated System Peripheral**
- **On-Chip Debugging Support Including Break Point Registers**
- **Complete Intel Development Support**
  - **— C, PL/M, Assembler**
  - **— ICE™-376, In-Circuit Emulator**
  - **— iRMK™ Real Time Kernel**
  - **— iSDM™ Debug Monitor**
  - **— DOS Based Debug**
- **Extensive Third-Party Support:**
  - **— Languages: C, Pascal, FORTRAN, BASIC and ADA***
  - **— Hosts: VMS*, UNIX*, MS-DOS*, and Others**
  - **— Real-Time Kernels**
- **High Speed CHMOS IV Technology**
- **Available in 100 Pin Plastic Quad Flat-Pack Package and 88-Pin Pin Grid Array**
  (See Packaging Outlines and Dimensions #231369)

INTRODUCTION

The 376 32-bit embedded processor is designed for high performance embedded systems. It provides the performance benefits of a highly pipelined 32-bit internal architecture with the low system cost associated with 16-bit hardware systems. The 80376 processor is based on the 80386 and offers a high degree of compatibility with the 80386. All 80386 32-bit programs not dependent on paging can be executed on the 80376 and all 80376 programs can be executed on the 80386. All 32-bit 80386 language translators can be used for software development. With proper support software, any 80386-based computer can be used to develop and test 80376 programs. In addition, any 80386-based PC-AT* compatible computer can be used for hardware prototyping for designs based on the 80376 and its companion product the 82370.



80376 Microarchitecture

Intel, iRMK, ICE, 376, 386, Intel386, iSDM, Intel1376 are trademarks of Intel Corp.
*UNIX is a registered trademark of AT&T.
ADA is a registered trademark of the U.S. Government, Ada Joint Program Office.
PC-AT is a registered trademark of IBM Corporation.
VMS is a trademark of Digital Equipment Corporation.
MS-DOS is a trademark of MicroSoft Corporation.

9

July 1990
Order Number: 240182-004

1.0 PIN DESCRIPTION

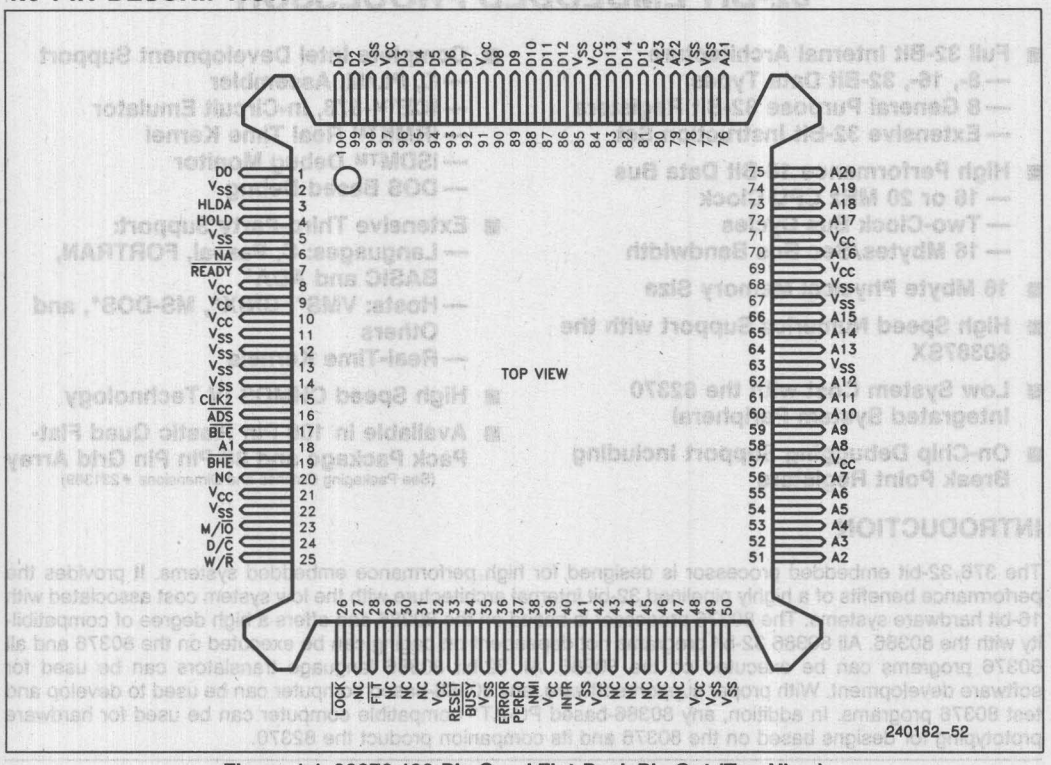


Figure 1.1. 80376 100-Pin Quad Flat-Pack Pin Out (Top View)

Table 1.1. 100-Pin Plastic Quad Flat-Pack Pin Assignments

Address		Data		Control		N/C	V_{CC}	V_{SS}
A_1	18	D_0	1	$\overline{ADS}$	16	20	8	2
A_2	51	D_1	100	$\overline{BHE}$	19	27	9	5
A_3	52	D_2	99	$\overline{BLE}$	17		10	11
A_4	53	D_3	96	$\overline{BUSY}$	34	29	21	12
A_5	54	D_4	95	CLK2	15	30	32	13
A_6	55	D_5	94	D/$\overline{C}$	24	31	39	14
A_7	56	D_6	93	$\overline{ERROR}$	36	43	42	22
A_8	58	D_7	92	$\overline{FLT}$	28	44	48	35
A_9	59	D_8	90	HLDA	3	45	57	41
A_{10}	60	D_9	89	HOLD	4	46	69	49
A_{11}	61	D_{10}	88	INTR	40	47	71	50
A_{12}	62	D_{11}	87	$\overline{LOCK}$	26		84	63
A_{13}	64	D_{12}	86	M/$\overline{IO}$	23		91	67
A_{14}	65	D_{13}	83	$\overline{NA}$	6		97	68
A_{15}	66	D_{14}	82	NMI	38			77
A_{16}	70	D_{15}	81	PEREQ	37			78
A_{17}	72			$\overline{READY}$	7			85
A_{18}	73			RESET	33			98
A_{19}	74			W/$\overline{R}$	25			
A_{20}	75							
A_{21}	76							
A_{22}	79							
A_{23}	80							

Top View
(Component Side)

	N	M	L	K	J	H	G	F	E	D	C	B	A	
1	V_{CC}	V_{SS}	N/C	A1	$\overline{ADS}$	$\overline{READY}$	HOLD	D0	D2	V_{SS}	V_{CC}	V_{SS}	V_{CC}	1
2	V_{SS}	V_{CC}	M/$\overline{IO}$	$\overline{BHE}$	$\overline{BLE}$	CLK2	$\overline{NA}$	HLDA	D1	D3	V_{SS}	V_{CC}	V_{SS}	2
3	V_{CC}	D/$\overline{C}$										D4	V_{CC}	3
4	V_{SS}	W/$\overline{R}$										D6	D5	4
5	V_{CC}	$\overline{LOCK}$										D7	D8	5
6	V_{SS}	RESET										D9	D10	6
7	PEREQ	$\overline{BUSY}$										D11	D12	7
8	$\overline{ERROR}$	NMI										D13	D14	8
9	V_{SS}	INTR										D15	A23	9
10	V_{CC}	A2										A21	A22	10
11	V_{SS}	A3										V_{SS}	V_{CC}	11
12	V_{SS}	A4	A5	A7	A8	A10	A13	A15	A17	A18	A20	V_{CC}	V_{SS}	12
13	V_{CC}	V_{SS}	V_{CC}	A6	A9	A11	A12	A14	A16	A19	V_{CC}	V_{SS}	V_{CC}	13
	N	M	L	K	J	H	G	F	E	D	C	B	A	

240182-49

Bottom View
(Pin Side)

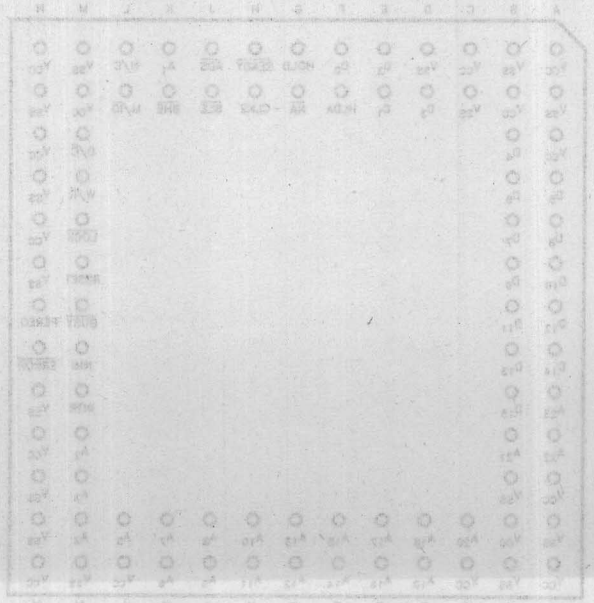
	A	B	C	D	E	F	G	H	J	K	L	M	N	
01	V_{CC}	V_{SS}	V_{CC}	V_{SS}	D_2	D_0	HOLD	$\overline{READY}$	$\overline{ADS}$	A_1	N/C	V_{SS}	V_{CC}	01
02	V_{SS}	V_{CC}	V_{SS}	D_3	D_1	HLDA	$\overline{NA}$	CLK2	$\overline{BLE}$	$\overline{BHE}$	M/$\overline{IO}$	V_{CC}	V_{SS}	02
03	V_{CC}	D_4										D/$\overline{C}$	V_{CC}	03
04	D_5	D_6										W/$\overline{R}$	V_{SS}	04
05	D_8	D_7										$\overline{LOCK}$	V_{CC}	05
06	D_{10}	D_9										RESET	V_{SS}	06
07	D_{12}	D_{11}										$\overline{BUSY}$	PEREQ	07
08	D_{14}	D_{13}										NMI	$\overline{ERROR}$	08
09	A_{23}	D_{15}										INTR	V_{SS}	09
10	A_{22}	A_{21}										A_2	V_{CC}	10
11	V_{CC}	V_{SS}										A_3	V_{SS}	11
12	V_{SS}	V_{CC}	A_{20}	A_{18}	A_{17}	A_{15}	A_{13}	A_{10}	A_8	A_7	A_5	A_4	V_{SS}	12
13	V_{CC}	V_{SS}	V_{CC}	A_{19}	A_{16}	A_{14}	A_{12}	A_{11}	A_9	A_6	V_{CC}	V_{SS}	V_{CC}	13
	A	B	C	D	E	F	G	H	J	K	L	M	N	

240182-2

Figure 1.2. 80376 88-Pin Grid Array Pin Out

Table 1.2. 88-Pin Grid Array Pin Assignments

Pin	Label	Pin	Label	Pin	Label	Pin	Label
2H	CLK2	12D	A_{18}	2L	M/$\overline{IO}$	11A	V_{CC}
9B	D_{15}	12E	A_{17}	5M	$\overline{LOCK}$	13A	V_{CC}
8A	D_{14}	13E	A_{16}	1J	$\overline{ADS}$	13C	V_{CC}
8B	D_{13}	12F	A_{15}	1H	$\overline{READY}$	13L	V_{CC}
7A	D_{12}	13F	A_{14}	2G	$\overline{NA}$	1N	V_{CC}
7B	D_{11}	12G	A_{13}	1G	HOLD	13N	V_{CC}
6A	D_{10}	13G	A_{12}	2F	HLDA	11B	V_{SS}
6B	D_9	13H	A_{11}	7N	PEREQ	2C	V_{SS}
5A	D_8	12H	A_{10}	7M	$\overline{BUSY}$	1D	V_{SS}
5B	D_7	13J	A_9	8N	$\overline{ERROR}$	1M	V_{SS}
4B	D_6	12J	A_8	9M	INTR	4N	V_{SS}
4A	D_5	12K	A_7	8M	NMI	9N	V_{SS}
3B	D_4	13K	A_6	6M	RESET	11N	V_{SS}
2D	D_3	12L	A_5	2B	V_{CC}	2A	V_{SS}
1E	D_2	12M	A_4	12B	V_{CC}	12A	V_{SS}
2E	D_1	11M	A_3	1C	V_{CC}	1B	V_{SS}
1F	D_0	10M	A_2	2M	V_{CC}	13B	V_{SS}
9A	A_{23}	1K	A_1	3N	V_{CC}	13M	V_{SS}
10A	A_{22}	2J	$\overline{BLE}$	5N	V_{CC}	2N	V_{SS}
10B	A_{21}	2K	$\overline{BHE}$	10N	V_{CC}	6N	V_{SS}
12C	A_{20}	4M	W/$\overline{R}$	1A	V_{CC}	12N	V_{SS}
13D	A_{19}	3M	D/$\overline{C}$	3A	V_{CC}	1L	N/C



The following table lists a brief description of each pin on the 80376. The following definitions are used in these descriptions:

$\overline{\ }$ The named signal is active LOW.
I Input signal.
O Output signal.
I/O Input and Output signal.
— No electrical connection.

Symbol	Type	Name and Function
CLK2	I	**CLK2** provides the fundamental timing for the 80376. For additional information see **Clock** in Section 4.1.
RESET	I	**RESET** suspends any operation in progress and places the 80376 in a known reset state. See **Interrupt Signals** in Section 4.1 for additional information.
D_{15}–D_0	I/O	**DATA BUS** inputs data during memory, I/O and interrupt acknowledge read cycles and outputs data during memory and I/O write cycles. See **Data Bus** in Section 4.1 for additional information.
A_{23}–A_1	O	**ADDRESS BUS** outputs physical memory or port I/O addresses. See **Address Bus** in Section 4.1 for additional information.
W/$\overline{R}$	O	**WRITE/READ** is a bus cycle definition pin that distinguishes write cycles from read cycles. See **Bus Cycle Definition Signals** in Section 4.1 for additional information.
D/$\overline{C}$	O	**DATA/CONTROL** is a bus cycle definition pin that distinguishes data cycles, either memory or I/O, from control cycles which are: interrupt acknowledge, halt, and instruction fetching. See **Bus Cycle Definition Signals** in Section 4.1 for additional information.
M/$\overline{IO}$	O	**MEMORY I/O** is a bus cycle definition pin that distinguishes memory cycles from input/output cycles. See **Bus Cycle Definition Signals** in Section 4.1 for additional information.
$\overline{LOCK}$	O	**BUS LOCK** is a bus cycle definition pin that indicates that other system bus masters are denied access to the system bus while it is active. See **Bus Cycle Definition Signals** in Section 4.1 for additional information.
$\overline{ADS}$	O	**ADDRESS STATUS** indicates that a valid bus cycle definition and address (W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{BHE}$, $\overline{BLE}$ and A_{23}–A_1) are being driven at the 80376 pins. See **Bus Control Signals** in Section 4.1 for additional information.
$\overline{NA}$	I	**NEXT ADDRESS** is used to request address pipelining. See **Bus Control Signals** in Section 4.1 for additional information.
$\overline{READY}$	I	**BUS READY** terminates the bus cycle. See **Bus Control Signals** in Section 4.1 for additional information.
$\overline{BHE}$, $\overline{BLE}$	O	**BYTE ENABLES** indicate which data bytes of the data bus take part in a bus cycle. See **Address Bus** in Section 4.1 for additional information.
HOLD	I	**BUS HOLD REQUEST** input allows another bus master to request control of the local bus. See **Bus Arbitration Signals** in Section 4.1 for additional information.

Symbol	Type	Name and Function
HLDA	O	**BUS HOLD ACKNOWLEDGE** output indicates that the 80376 has surrendered control of its local bus to another bus master. See **Bus Arbitration Signals** in Section 4.1 for additional information.
INTR	I	**INTERRUPT REQUEST** is a maskable input that signals the 80376 to suspend execution of the current program and execute an interrupt acknowledge function. See **Interrupt Signals** in Section 4.1 for additional information.
NMI	I	**NON-MASKABLE INTERRUPT REQUEST** is a non-maskable input that signals the 80376 to suspend execution of the current program and execute an interrupt acknowledge function. See **Interrupt Signals** in Section 4.1 for additional information.
$\overline{BUSY}$	I	**BUSY** signals a busy condition from a processor extension. See **Coprocessor Interface Signals** in Section 4.1 for additional information.
$\overline{ERROR}$	I	**ERROR** signals an error condition from a processor extension. See **Coprocessor Interface Signals** in Section 4.1 for additional information.
PEREQ	I	**PROCESSOR EXTENSION REQUEST** indicates that the processor extension has data to be transferred by the 80376. See **Coprocessor Interface Signals** in Section 4.1 for additional information.
$\overline{FLT}$	I	**FLOAT,** when active, forces all bidirectional and output signals, including HLDA, to the float condition. FLOAT is not available on the PGA package. See **Float** for additional information.
N/C	—	**NO CONNECT** should always remain unconnected. Connection of a N/C pin may cause the processor to malfunction or be incompatible with future steppings of the 80376.
V_{CC}	I	**SYSTEM POWER** provides the +5V nominal D.C. supply input.
V_{SS}	I	**SYSTEM GROUND** provides 0V connection from which all inputs and outputs are measured.

2.0 ARCHITECTURE OVERVIEW

The 80376 supports the protection mechanisms needed by sophisticated multitasking embedded systems and real-time operating systems. The use of these protection mechanisms is completely optional. For embedded applications not needing protection, the 80376 can easily be configured to provide a 16 Mbyte physical address space.

Instruction pipelining, high bus bandwidth, and a very high performance ALU ensure short average instruction execution times and high system throughput. The 80376 is capable of execution at sustained rates of 2.5–3.0 million instructions per second.

The 80376 offers on-chip testability and debugging features. Four break point registers allow conditional or unconditional break point traps on code execution or data accesses for powerful debugging of even ROM based systems. Other testability features include self-test and tri-stating of output buffers during RESET.

The Intel 80376 embedded processor consists of a central processing unit, a memory management unit and a bus interface. The central processing unit consists of the execution unit and instruction unit. The execution unit contains the eight 32-bit general registers which are used for both address calculation and data operations and a 64-bit barrel shifter used to speed shift, rotate, multiply, and divide operations. The instruction unit decodes the instruction opcodes and stores them in the decoded instruction queue for immediate use by the execution unit.

The Memory Management Unit (MMU) consists of a segmentation and protection unit. Segmentation allows the managing of the logical address space by providing an extra addressing component, one that allows easy code and data relocatability, and efficient sharing.

The protection unit provides four levels of protection for isolating and protecting applications and the operating system from each other. The hardware enforced protection allows the design of systems with a high degree of integrity and simplifies debugging.

Finally, to facilitate high performance system hardware designs, the 80376 bus interface offers address pipelining and direct Byte Enable signals for each byte of the data bus.

2.1 Register Set

The 80376 has twenty-nine registers as shown in Figure 2.1. These registers are grouped into the following six categories:

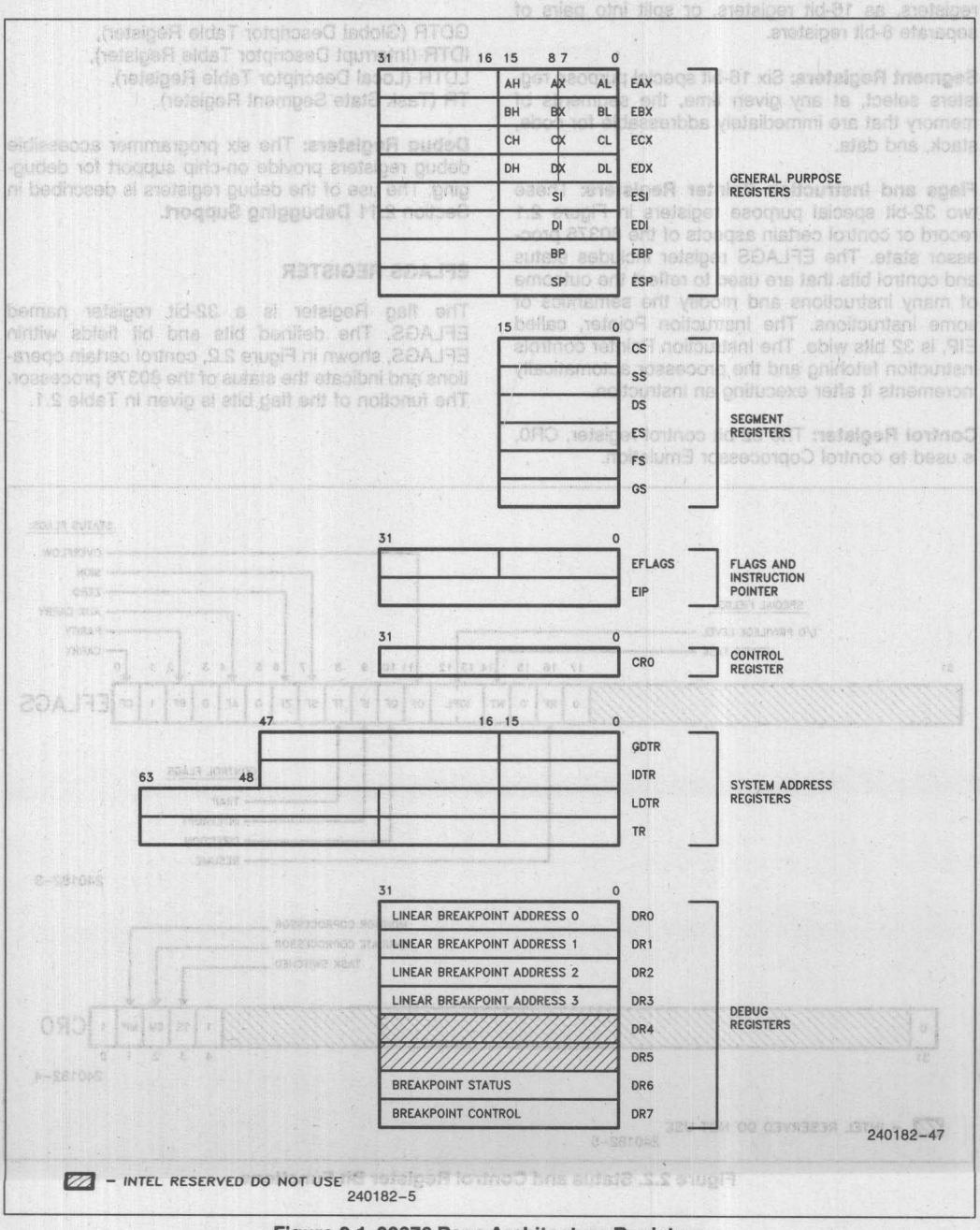


Figure 2.1. 80376 Base Architecture Registers

General Registers: The eight 32-bit general purpose registers are used to contain arithmetic and logical operands. Four of these (EAX, EBX, ECX and EDX) can be used either in their entirety as 32-bit registers, as 16-bit registers, or split into pairs of separate 8-bit registers.

Segment Registers: Six 16-bit special purpose registers select, at any given time, the segments of memory that are immediately addressable for code, stack, and data.

Flags and Instruction Pointer Registers: These two 32-bit special purpose registers in Figure 2.1 record or control certain aspects of the 80376 processor state. The EFLAGS register includes status and control bits that are used to reflect the outcome of many instructions and modify the semantics of some instructions. The Instruction Pointer, called EIP, is 32 bits wide. The Instruction Pointer controls instruction fetching and the processor automatically increments it after executing an instruction.

Control Register: The 32-bit control register, CR0, is used to control Coprocessor Emulation.

System Address Registers: These four special registers reference the tables or segments supported by the 80376/80386 protection model. These tables or segments are:

GDTR (Global Descriptor Table Register),
IDTR (Interrupt Descriptor Table Register),
LDTR (Local Descriptor Table Register),
TR (Task State Segment Register).

Debug Registers: The six programmer accessible debug registers provide on-chip support for debugging. The use of the debug registers is described in Section 2.11 **Debugging Support**.

EFLAGS REGISTER

The flag Register is a 32-bit register named EFLAGS. The defined bits and bit fields within EFLAGS, shown in Figure 2.2, control certain operations and indicate the status of the 80376 processor. The function of the flag bits is given in Table 2.1.

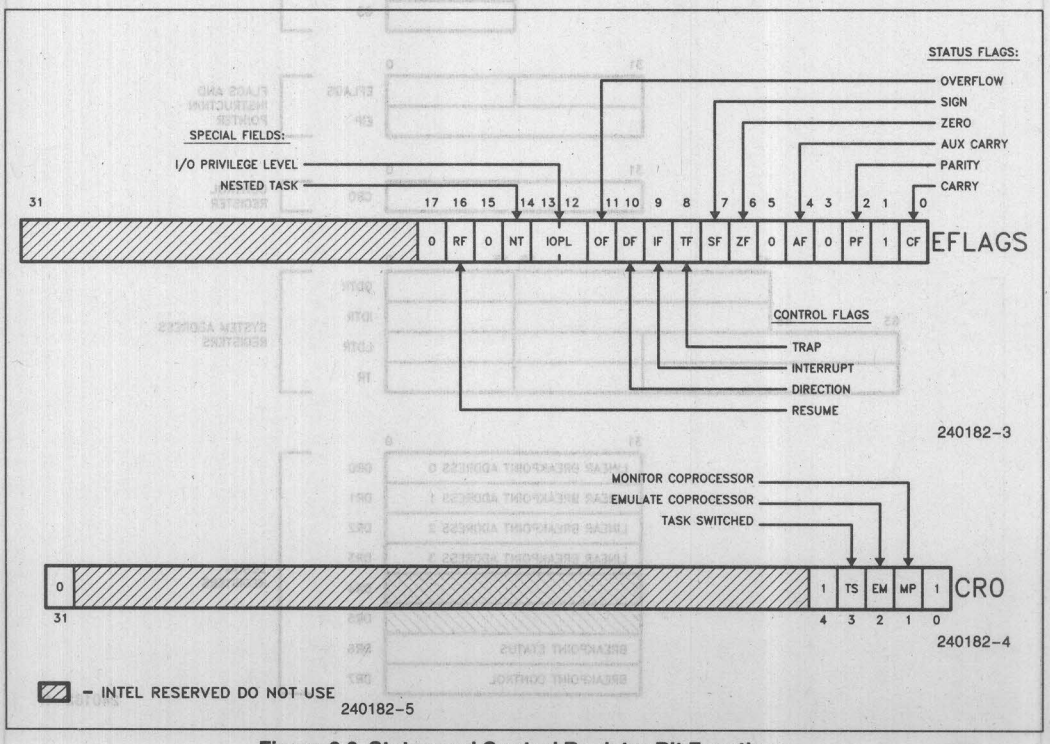


Figure 2.2. Status and Control Register Bit Functions

Table 2.1. Flag Definitions

Bit Position	Name	Function
0	CF	**Carry Flag**—Set on high-order bit carry or borrow; cleared otherwise.
2	PF	**Parity Flag**—Set if low-order 8 bits of result contain an even number of 1-bits; cleared otherwise.
4	AF	**Auxiliary Carry Flag**—Set on carry from or borrow to the low order four bits of AL; cleared otherwise.
6	ZF	**Zero Flag**—Set if result is zero; cleared otherwise.
7	SF	**Sign Flag**—Set equal to high-order bit of result (0 if positive, 1 if negative).
8	TF	**Single Step Flag**—Once set, a single step interrupt occurs after the next instruction executes. TF is cleared by the single step interrupt.
9	IF	**Interrupt-Enable Flag**—When set, external interrupts signaled on the INTR pin will cause the CPU to transfer control to an interrupt vector specified location.
10	DF	**Direction Flag**—Causes string instructions to auto-increment (default) the appropriate index registers when cleared. Setting DF causes auto-decrement.
11	OF	**Overflow Flag**—Set if the operation resulted in a carry/borrow into the sign bit (high-order bit) of the result but did not result in a carry/borrow out of the high-order bit or vice-versa.
12, 13	IOPL	**I/O Privilege Level**—Indicates the maximum CPL permitted to execute I/O instructions without generating an exception 13 fault or consulting the I/O permission bit map. It also indicates the maximum CPL value allowing alteration of the IF bit.
14	NT	**Nested Task**—Indicates that the execution of the current task is nested within another task (see **Task Switching**).
16	RF	**Resume Flag**—Used in conjunction with debug register breakpoints. It is checked at instruction boundaries before breakpoint processing. If set, any debug fault is ignored on the next instruction. It is reset at the successful completion of any instruction except IRET, POPF, and those instructions causing task switches.

CONTROL REGISTER

The 80376 has a 32-bit control register called CR0 that is used to control coprocessor emulation. This register is shown in Figures, 2.1 and 2.2. The defined CR0 bits are described in Table 2.2. Bits 0, 4 and 31 of CR0 have fixed values in the 80376. These values cannot be changed. Programs that load CR0 should always load bits 0, 4 and 31 with values previously there to be compatible with the 80386.

Table 2.2. CR0 Definitions

Bit Position	Name	Function
1	MP	**Monitor Coprocessor Extension**—Allows WAIT instructions to cause a processor extension not present exception (number 7).
2	EM	**Emulate Processor Extension**—When set, this bit causes a processor extension not present exception (number 7) on ESC instructions to allow processor extension emulation.
3	TS	**Task Switched**—When set, this bit indicates the next instruction using a processor extension will cause exception 7, allowing software to test whether the current processor extension context belongs to the current task (see **Task Switching**).

2.2 Instruction Set

The instruction set is divided into nine categories of operations:

- Data Transfer
- Arithmetic
- Shift/Rotate
- String Manipulation
- Bit Manipulation
- Control Transfer
- High Level Language Support
- Operating System Support
- Processor Control

These 80376 processor instructions are listed in Table 8.1 **80376 Instruction Set and Clock Count Summary**.

All 80376 processor instructions operate on either 0, 1, 2 or 3 operands; an operand resides in a register, in the instruction itself, or in memory. Most zero operand instructions (e.g. CLI, STI) take only one byte. One operand instructions generally are two bytes long. The average instruction is 3.2 bytes long. Since the 80376 has a 16-byte prefetch instruction queue an average of 5 instructions can be prefetched. The use of two operands permits the following types of common instructions:

- Register to Register
- Memory to Register
- Immediate to Register
- Memory to Memory
- Register to Memory
- Immediate to Memory

The operands are either 8-, 16- or 32-bit long.

2.3 Memory Organization

Memory on the 80376 is divided into 8-bit quantities (bytes), 16-bit quantities (words), and 32-bit quantities (dwords). Words are stored in two consecutive bytes in memory with the low-order byte at the lowest address. Dwords are stored in four consecutive bytes in memory with the low-order byte at the lowest address. The address of a word or Dword is the byte address of the low-order byte. For maximum performance word and dword values should be at even physical addresses.

In addition to these basic data types the 80376 processor supports segments. Memory can be divided up into one or more variable length segments, which can be shared between programs.

ADDRESS SPACES

The 80376 has three types of address spaces: **logical, linear,** and **physical.** A **logical** address (also known as a **virtual** address) consists of a selector and an offset. A selector is the contents of a segment register. An offset is formed by summing all of the addressing components (BASE, INDEX, and DISPLACEMENT), discussed in Section 2.4 **Addressing Modes,** into an effective address.

Every selector has a **logical base** address associated with it that can be up to 32 bits in length. This 32-bit **logical base** address is added to either a 32-bit offset address or a 16-bit offset address (by using the ***address length prefix***) to form a final 32-bit **linear** address. This final **linear** address is then truncated so that only the lower 24 bits of this address are used to address the 16 Mbytes physical memory address space. The **logical base** address is stored in one of two operating system tables (i.e. the Local Descriptor Table or Global Descriptor Table).

Figure 2.3 shows the relationship between the various address spaces.

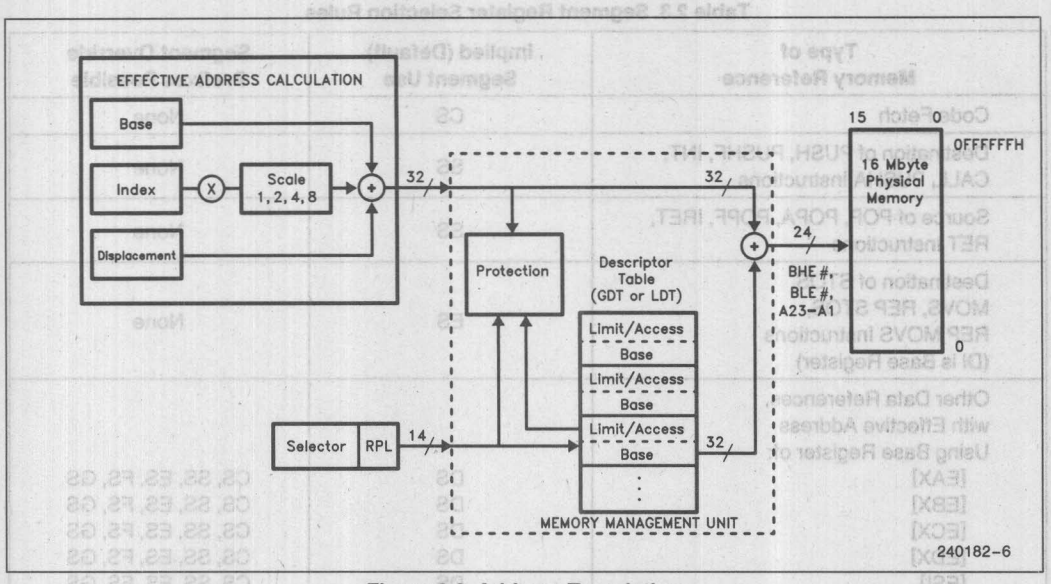


Figure 2.3. Address Translation

SEGMENT REGISTER USAGE

The main data structure used to organize memory is the segment. On the 80376, segments are variable sized blocks of linear addresses which have certain attributes associated with them. There are two main types of segments, code and data. The simplest use of segments is to have one code and data segment. Each segment is 16 Mbytes in size overlapping each other. This allows code and data to be directly addressed by the same offset.

In order to provide compact instruction encoding and increase processor performance, instructions do not need to explicitly specify which segment register is used. The segment register is automatically chosen according to the rules of Table 2.3 (Segment Register Selection Rules). In general, data references use the selector contained in the DS register, stack references use the SS register and instruction fetches use the CS register. The contents of the Instruction Pointer provide the offset. Special segment override prefixes allow the explicit use of a given segment register, and override the implicit rules listed in Table 2.3. The override prefixes also allow the use of the ES, FS and GS segment registers.

There are no restrictions regarding the overlapping of the base addresses of any segments. Thus, all 6 segments could have the base address set to zero. Further details of segmentation are discussed in Section 3.0 Architecture.

9

Table 2.3. Segment Register Selection Rules

Type of Memory Reference	Implied (Default) Segment Use	Segment Override Prefixes Possible
Code Fetch	CS	None
Destination of PUSH, PUSHF, INT, CALL, PUSHA Instructions	SS	None
Source of POP, POPA, POPF, IRET, RET Instructions	SS	None
Destination of STOS, MOVS, REP STOS, REP MOVS Instructions (DI is Base Register)	ES	None
Other Data References, with Effective Address Using Base Register of:		
[EAX]	DS	CS, SS, ES, FS, GS
[EBX]	DS	CS, SS, ES, FS, GS
[ECX]	DS	CS, SS, ES, FS, GS
[EDX]	DS	CS, SS, ES, FS, GS
[ESI]	DS	CS, SS, ES, FS, GS
[EDI]	DS	CS, SS, ES, FS, GS
[EBP]	SS	CS, SS, ES, FS, GS
[ESP]	SS	CS, SS, ES, FS, GS

2.4 Addressing Modes

The 80376 provides a total of 8 addressing modes for instructions to specify operands. The addressing modes are optimized to allow the efficient execution of high level languages such as C and FORTRAN, and they cover the vast majority of data references needed by high-level languages.

Two of the addressing modes provide for instructions that operate on register or immediate operands:

Register Operand Mode: The operand is located in one of the 8-, 16- or 32-bit general registers.

Immediate Operand Mode: The operand is included in the instruction as part of the opcode.

The remaining 6 modes provide a mechanism for specifying the effective address of an operand. The linear address consists of two components: the segment base address and an effective address. The effective address is calculated by summing any combination of the following three address elements (see Figure 2.3):

DISPLACEMENT: an 8-, 16- or 32-bit immediate value following the instruction.

BASE: The contents of any general purpose register. The base registers are generally used by compilers to point to the start of the local variable area. Note that if the ***Address Length Prefix*** is used, only BX and BP can be used as a BASE register.

INDEX: The contents of any general purpose register except for ESP. The index registers are used to access the elements of an array, or a string of characters. The index register's value can be multiplied by a scale factor, either 1, 2, 4 or 8. The scaled index is especially useful for accessing arrays or structures. Note that if the ***Address Length Prefix*** is used, no Scaling is available and only the registers SI and DI can be used to INDEX.

Combinations of these 3 components make up the 6 additional addressing modes. There is no performance penalty for using any of these addressing combinations, since the effective address calculation is pipelined with the execution of other instructions. The one exception is the simultaneous use of BASE and INDEX components which requires one additional clock.

As shown in Figure 2.4, the effective address (EA) of an operand is calculated according to the following formula:

$$EA = BASE_{Register} + (INDEX_{Register} \times scaling) + DISPLACEMENT$$

1. **Direct Mode:** The operand's offset is contained as part of the instruction as an 8-, 16- or 32-bit DISPLACEMENT.
2. **Register Indirect Mode:** A BASE register contains the address of the operand.
3. **Based Mode:** A BASE register's contents is added to a DISPLACEMENT to form the operand's offset.
4. **Scaled Index Mode:** An INDEX register's contents is multiplied by a SCALING factor which is added to a DISPLACEMENT to form the operand's offset.
5. **Based Scaled Index Mode:** The contents of an INDEX register is multiplied by a SCALING factor and the result is added to the contents of a BASE register to obtain the operand's offset.
6. **Based Scaled Index Mode with Displacement:** The contents of an INDEX register are multiplied by a SCALING factor, and the result is added to the contents of a BASE register and a DISPLACEMENT to form the operand's offset.

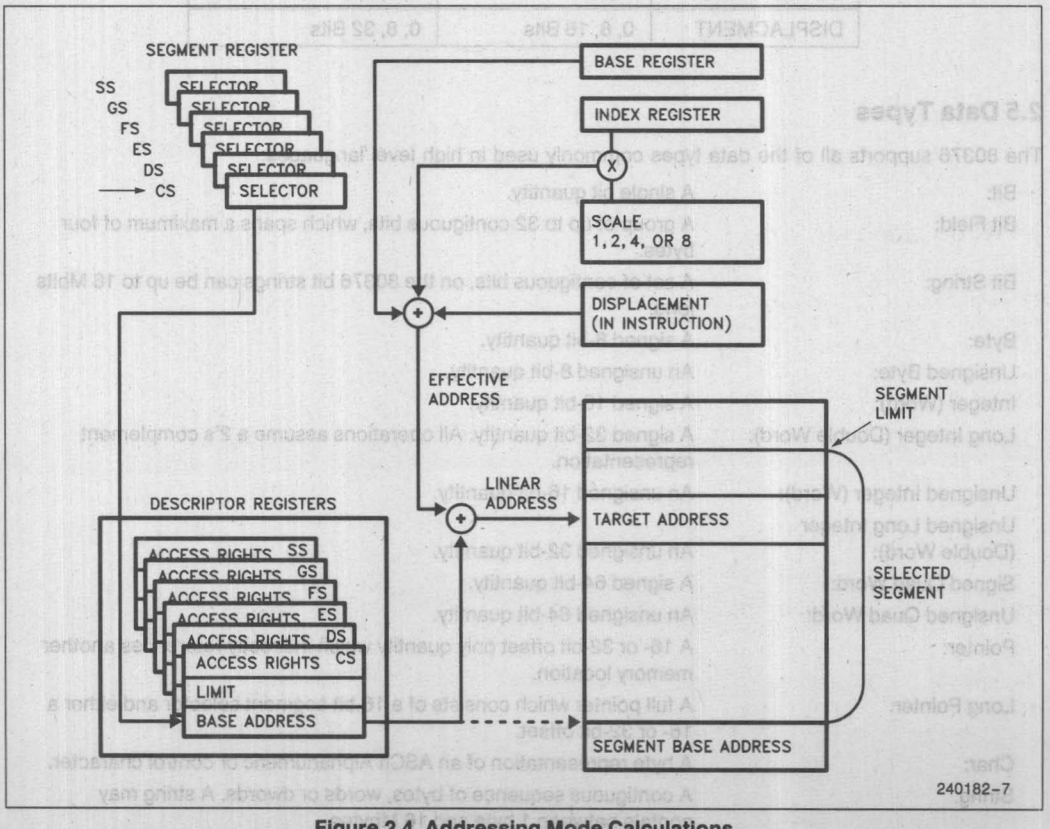


Figure 2.4. Addressing Mode Calculations

GENERATING 16-BIT ADDRESSES

The 80376 executes code with a default length for operands and addresses of 32 bits. The 80376 is also able to execute operands and addresses of 16 bits. This is specified through the use of override prefixes. Two prefixes, the **Operand Length Prefix** and the **Address Length Prefix,** override the default 32-bit length on an individual instruction basis. These prefixes are automatically added by assemblers. The Operand Length and Address Length Prefixes can be applied separately or in combination to any instruction.

The 80376 normally executes 32-bit code and uses either 8- or 32-bit displacements, and any register can be used as based or index registers. When executing 16-bit code (by prefix overrides), the displacements are either 8 or 16 bits, and the base and index register conform to the 16-bit model. Table 2.4 illustrates the differences.

Table 2.4. BASE and INDEX Registers for 16- and 32-Bit Addresses

	16-Bit Addressing	32-Bit Addressing
BASE REGISTER	BX, BP	Any 32-Bit GP Register
INDEX REGISTER	SI, DI	Any 32-Bit GP Register except ESP
SCALE FACTOR	None	1, 2, 4, 8
DISPLACMENT	0, 8, 16 Bits	0, 8, 32 Bits

2.5 Data Types

The 80376 supports all of the data types commonly used in high level languages:

Bit:	A single bit quantity.
Bit Field:	A group of up to 32 contiguous bits, which spans a maximum of four bytes.
Bit String:	A set of contiguous bits, on the 80376 bit strings can be up to 16 Mbits long.
Byte:	A signed 8-bit quantity.
Unsigned Byte:	An unsigned 8-bit quantity.
Integer (Word):	A signed 16-bit quantity.
Long Integer (Double Word):	A signed 32-bit quantity. All operations assume a 2's complement representation.
Unsigned Integer (Word):	An unsigned 16-bit quantity.
Unsigned Long Integer (Double Word):	An unsigned 32-bit quantity.
Signed Quad Word:	A signed 64-bit quantity.
Unsigned Quad Word:	An unsigned 64-bit quantity.
Pointer:	A 16- or 32-bit offset only quantity which indirectly references another memory location.
Long Pointer:	A full pointer which consists of a 16-bit segment selector and either a 16- or 32-bit offset.
Char:	A byte representation of an ASCII Alphanumeric or control character.
String:	A contiguous sequence of bytes, words or dwords. A string may contain between 1 byte and 16 Mbytes.
BCD:	A byte (unpacked) representation of decimal digits 0–9.
Packed BCD:	A byte (packed) representation of two decimal digits 0–9 storing one digit in each nibble.

When the 80376 is coupled with a numerics Coprocessor such as the 80387SX then the following common Floating Point types are supported.

Floating Point: A signed 32-, 64- or 80-bit real number representation. Floating point numbers are supported by the 80387SX numerics coprocessor.

Figure 2.5 illustrates the data types supported by the 80376 processor and the 80387SX coprocessor.

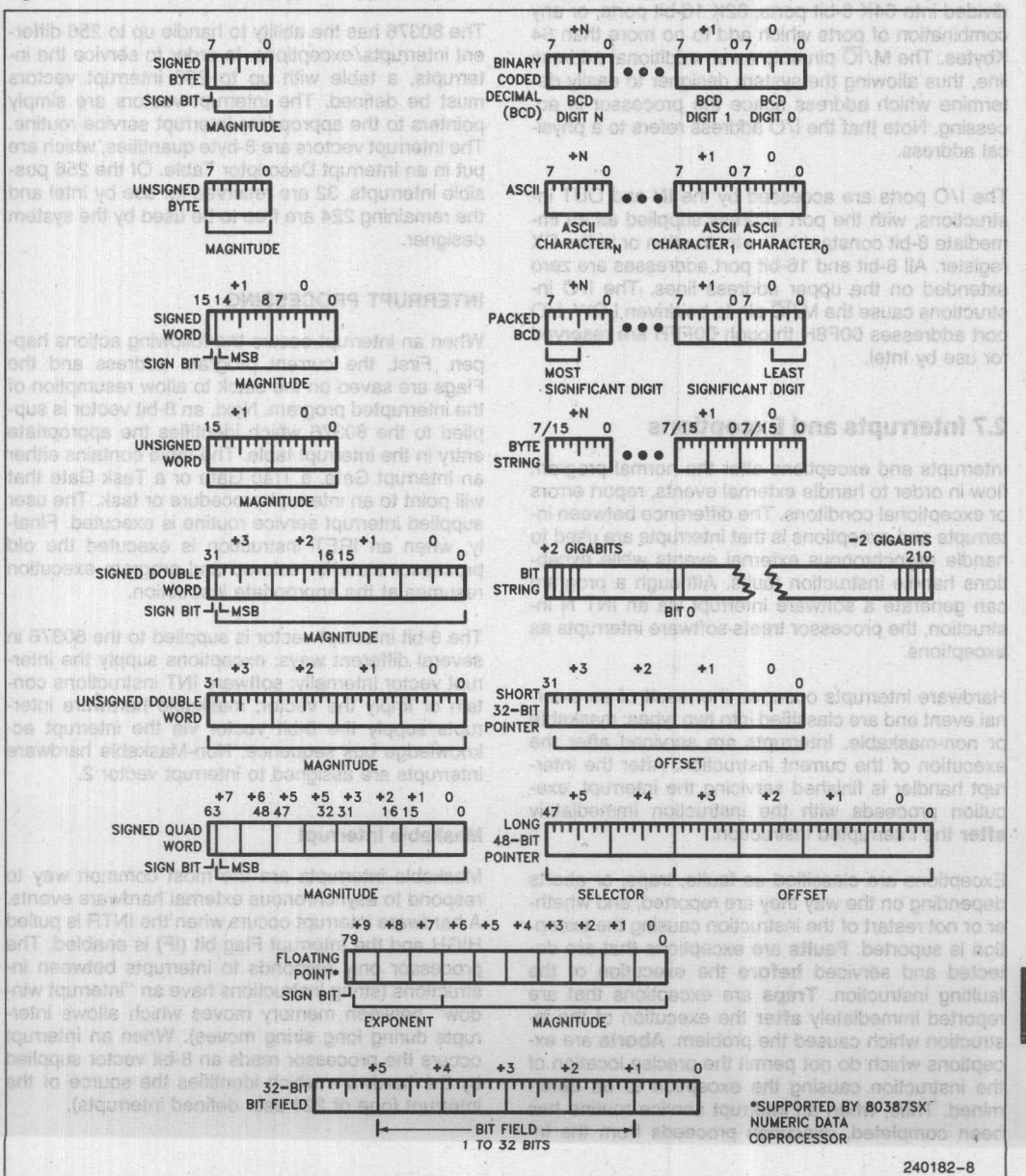


Figure 2.5. 80376 Supported Data Types

2.6 I/O Space

The 80376 has two distinct physical address spaces: physical memory and I/O. Generally, peripherals are placed in I/O space although the 80376 also supports memory-mapped peripherals. The I/O space consists of 64 Kbytes which can be divided into 64K 8-bit ports, 32K 16-bit ports, or any combination of ports which add to no more than 64 Kbytes. The M/$\overline{IO}$ pin acts as an additional address line, thus allowing the system designer to easily determine which address space the processor is accessing. Note that the I/O address refers to a physical address.

The I/O ports are accessed by the IN and OUT instructions, with the port address supplied as an immediate 8-bit constant in the instruction or in the DX register. All 8-bit and 16-bit port addresses are zero extended on the upper address lines. The I/O instructions cause the M/$\overline{IO}$ pin to be driven LOW. I/O port addresses 00F8H through 00FFH are reserved for use by Intel.

2.7 Interrupts and Exceptions

Interrupts and exceptions alter the normal program flow in order to handle external events, report errors or exceptional conditons. The difference between interrupts and exceptions is that interrupts are used to handle asynchronous external events while exceptions handle instruction faults. Although a program can generate a software interrupt via an INT N instruction, the processor treats software interrupts as exceptions.

Hardware interrupts occur as the result of an external event and are classified into two types: maskable or non-maskable. Interrupts are serviced after the execution of the current instruction. After the interrupt handler is finished servicing the interrupt, execution proceeds with the instruction immediately **after** the interrupted instruction.

Exceptions are classified as faults, traps, or aborts depending on the way they are reported, and whether or not restart of the instruction causing the exception is suported. **Faults** are exceptions that are detected and serviced **before** the execution of the faulting instruction. **Traps** are exceptions that are reported immediately **after** the execution of the instruction which caused the problem. **Aborts** are exceptions which do not permit the precise location of the instruction causing the exception to be determined. Thus, when an interrupt service routine has been completed, execution proceeds from the instruction immediately following the interrupted instruction. On the other hand the return address from an exception/fault routine will always point at the instruction causing the exception and include any leading instruction prefixes. Table 2.5 summarizes the possible interrupts for the 80376 and shows where the return address points to.

The 80376 has the ability to handle up to 256 different interrupts/exceptions. In order to service the interrupts, a table with up to 256 interrupt vectors must be defined. The interrupt vectors are simply pointers to the appropriate interrupt service routine. The interrupt vectors are 8-byte quantities, which are put in an Interrupt Descriptor Table. Of the 256 possible interrupts, 32 are reserved for use by Intel and the remaining 224 are free to be used by the system designer.

INTERRUPT PROCESSING

When an interrupt occurs the following actions happen. First, the current program address and the Flags are saved on the stack to allow resumption of the interrupted program. Next, an 8-bit vector is supplied to the 80376 which identifies the appropriate entry in the interrupt table. The table contains either an Interrupt Gate, a Trap Gate or a Task Gate that will point to an interrupt procedure or task. The user supplied interrupt service routine is executed. Finally, when an IRET instruction is executed the old processor state is restored and program execution resumes at the appropriate instruction.

The 8-bit interrupt vector is supplied to the 80376 in several different ways: exceptions supply the interrupt vector internally; software INT instructions contain or imply the vector; maskable hardware interrupts supply the 8-bit vector via the interrupt acknowledge bus sequence. Non-Maskable hardware interrupts are assigned to interrupt vector 2.

Maskable Interrupt

Maskable interrupts are the most common way to respond to asynchronous external hardware events. A hardware interrupt occurs when the INTR is pulled HIGH and the Interrupt Flag bit (IF) is enabled. The processor only responds to interrupts between instructions (string instructions have an "interrupt window" between memory moves which allows interrupts during long string moves). When an interrupt occurs the processor reads an 8-bit vector supplied by the hardware which identifies the source of the interrupt (one of 224 user defined interrupts).

Table 2.5. Interrupt Vector Assignments

Function	Interrupt Number	Instruction Which Can Cause Exception	Return Address Points to Faulting Instruction	Type
Divide Error	0	DIV, IDIV	Yes	FAULT
Debug Exception	1	Any Instruction	Yes	TRAP*
NMI Interrupt	2	INT 2 or NMI	No	NMI
One-Byte Interrupt	3	INT	No	TRAP
Interrupt on Overflow	4	INTO	No	TRAP
Array Bounds Check	5	BOUND	Yes	FAULT
Invalid OP-Code	6	Any Illegal Instruction	Yes	FAULT
Device Not Available	7	ESC, WAIT	Yes	FAULT
Double Fault	8	Any Instruction That Can Generate an Exception		ABORT
Coprocessor Segment Overrun	9	ESC	No	ABORT
Invalid TSS	10	JMP, CALL, IRET, INT	Yes	FAULT
Segment Not Present	11	Segment Register Instructions	Yes	FAULT
Stack Fault	12	Stack References	Yes	FAULT
General Protection Fault	13	Any Memory Reference	Yes	FAULT
Intel Reserved	14–15	—	—	—
Coprocessor Error	16	ESC, WAIT	Yes	FAULT
Intel Reserved	17–32			
Two-Byte Interrupt	0–255	INT n	No	TRAP

*Some debug exceptions may report both traps on the previous instruction, and faults on the next instruction.

Interrupts through Interrupt Gates automatically reset IF, disabling INTR requests. Interrupts through Trap Gates leave the state of the IF bit unchanged. Interrupts through a Task Gate change the IF bit according to the image of the EFLAGs register in the task's Task State Segment (TSS). When an IRET instruction is executed, the original state of the IF bit is restored.

Non-Maskable Interrupt

Non-maskable interrupts provide a method of servicing very high priority interrupts. When the NMI input is pulled HIGH it causes an interrupt with an internally supplied vector value of 2. Unlike a normal hardware interrupt no interrupt acknowledgement sequence is performed for an NMI.

While executing the NMI servicing procedure, the 80376 will not service any further NMI request, or INT requests, until an interrupt return (IRET) instruction is executed or the processor is reset. If NMI occurs while currently servicing an NMI, its presence will be saved for servicing after executing the first IRET instruction. The disabling of INTR requests depends on the gate in IDT location 2.

Software Interrupts

A third type of interrupt/exception for the 80376 is the software interrupt. An INT n instruction causes the processor to execute the interrupt service routine pointed to by the n^{th} vector in the interrupt table.

A special case of the two byte software interrupt INT n is the one byte INT 3, or breakpoint interrupt. By inserting this one byte instruction in a program, the user can set breakpoints in his program as a debugging tool.

9

A final type of software interrupt, is the single step interrupt. It is discussed in **Single-Step Trap** (page 22).

INTERRUPT AND EXCEPTION PRIORITIES

Interrupts are externally-generated events. Maskable Interrupts (on the INTR input) and Non-Maskable Interrupts (on the NMI input) are recognized at instruction boundaries. When NMI and maskable INTR are **both** recognized at the **same** instruction boundary, the 80376 invokes the NMI service routine first. If, after the NMI service routine has been invoked, maskable interrupts are still enabled, then the 80376 will invoke the appropriate interrupt service routine.

As the 80376 executes instructions, it follows a consistent cycle in checking for exceptions, as shown in Table 2.6. This cycle is repeated as each instruction is executed, and occurs in parallel with instruction decoding and execution.

INSTRUCTION RESTART

The 80376 fully supports restarting all instructions after faults. If an exception is detected in the instruction to be executed (exception categories 4 through 9 in Table 2.6), the 80376 device invokes the appropriate exception service routine. The 80376 is in a state that permits restart of the instruction.

DOUBLE FAULT

A Double fault (exception 8) results when the processor attempts to invoke an exception service routine for the segment exceptions (10, 11, 12 or 13), but in the process of doing so, detects an exception.

2.8 Reset and Initialization

When the processor is Reset the registers have the values shown in Table 2.7. The 80376 will then start executing instructions near the top of physical memory, at location 0FFFFF0H. A short JMP should be executed within the segment defined for power-up (see Table 2.7). The GDT should then be initialized for a start-up data and code segment followed by a far JMP that will load the segment descriptor cache with the new descriptor values. The IDT table, after reset, is located at physical address 0H, with a limit of 256 entries.

RESET forces the 80376 to terminate all execution and local bus activity. No instruction execution or bus activity will occur as long as Reset is active. Between 350 and 450 CLK2 periods after Reset becomes inactive, the 80376 will start executing instructions at the top of physical memory.

Table 2.6. Sequence of Exception Checking

Consider the case of the 80376 having just completed an instruction. It then performs the following checks before reaching the point where the next instruction is completed:

1. Check for Exception 1 Traps from the instruction just completed (single-step via Trap Flag, or Data Breakpoints set in the Debug Registers).
2. Check for external NMI and INTR.
3. Check for Exception 1 Faults in the next instruction (Instruction Execution Breakpoint set in the Debug Registers for the next instruction).
4. Check for Segmentation Faults that prevented fetching the entire next instruction (exceptions 11 or 13).
5. Check for Faults decoding the next instruction (exception 6 if illegal opcode; or exception 13 if instruction is longer than 15 bytes, or privilege violation (i.e. not at IOPL or at CPL = 0).
6. If WAIT opcode, check if TS = 1 and MP = 1 (exception 7 if both are 1).
7. If ESCape opcode for numeric coprocessor, check if EM = 1 or TS = 1 (exception 7 if either are 1).
8. If WAIT opcode or ESCape opcode for numeric coprocessor, check $\overline{\text{ERROR}}$ input signal (exception 16 if $\overline{\text{ERROR}}$ input is asserted).
9. Check for Segmentation Faults that prevent transferring the entire memory quantity (exceptions 11, 12, 13).

Table 2.7. Register Values after Reset

Flag Word (EFLAGS)	uuuu0002H	(Note 1)
Machine Status Word (CR0)	uuuuuuu1H	(Note 2)
Instruction Pointer (EIP)	0000FFF0H	
Code Segment (CS)	F000H	(Note 3)
Data Segment (DS)	0000H	(Note 4)
Stack Segment (SS)	0000H	
Extra Segment (ES)	0000H	(Note 4)
Extra Segment (FS)	0000H	
Extra Segment (GS)	0000H	
EAX Register	0000H	(Note 5)
EDX Register	Component and Stepping ID	(Note 6)
All Other Registers	Undefined	(Note 7)

NOTES:
1. EFLAG Register. The upper 14 bits of the EFLAGS register are undefined, all defined flag bits are zero.
2. CR0: The defined 4 bits in the CR0 is equal to 1H.
3. The Code Segment Register (CS) will have its Base Address set to 0FFFF0000H and Limit set to 0FFFFH.
4. The Data and Extra Segment Registers (DS and ES) will have their Base Address set to 000000000H and Limit set to 0FFFFH.
5. If self-test is selected, the EAX should contain a 0 value. If a value of 0 is not found the self-test has detected a flaw in the part.
6. EDX register always holds component and stepping identifier.
7. All unidentified bits are Intel Reserved and should not be used.

2.9 Initialization

Because the 80376 processor starts executing in protected mode, certain precautions need be taken during initialization. Before any far jumps can take place the GDT and/or LDT tables need to be setup and their respective registers loaded. Before interrupts can be initialized the IDT table must be setup and the IDTR must be loaded. The example code is shown below:

```
; ****************************************************************
;
; This is an example of startup code to put either an 80376,
; 80386SX or 80386 into flat mode. All of memory is treated as
; simple linear RAM. There are no interrupt routines. The
; Builder creates the GDT-alias and IDT-alias and places them,
; by default, in GDT[1] and GDT[2].  Other entries in the GDT
; are specified in the Build file.  After initialization it jumps
; to a C startup routine. To use this template, change this jmp
; address to that of your code, or make the label of your code
; "c_startup".
;
; This code was assembled and built using version 1.2 of the
; Intel RLL utilities and Intel 386ASM assembler.
;
;            ***    This code was tested    ***
;
; ****************************************************************
```

```
NAME FLAT                ; name of the object module

EXTRN    c_startup:near ; this is the label jmped to after init

pe_flag      equ 1
data_selc    equ 20h    ; assume code is GDT[3], data GDT[4]

INIT_CODE    SEGMENT ER PUBLIC USE32     ; Segment base at 0ffffff80h

PUBLIC GDT_DESC

gdt_desc     dq  ?

PUBLIC    START

start:
    cld                          ; clear direction flag
    smsw bx                      ; check for processor (80376) at reset
    test bl,1                    ; use SMSW rather than MOV for speed
    jnz pestart
realstart                        ; is an 80386 and in real mode
    db 66h                       ; force the next operand into 32-bit mode.
    mov eax,offset gdt_desc      ; move address of the GDT descriptor into eax
    xor ebx,ebx                  ; clear ebx
    mov bh,ah                    ; load 8 bits of address into bh
    move bl,al                   ; load 8 bits of address into bl
    db 67h
    db 66h                       ; use the 32-bit form of LGDT to load
    lgdt cs:[ebx]                ; the 32-bits of address into the GDTR
    smsw ax                      ; go into protected mode (set PE bit)
    or al,pe_flag
    lmsw ax
    jmp next                     ; flush prefetch queue
pestart:
    mov ebx,offset gdt_desc
    xor eax,eax
    mov ax,bx                    ; lower portion of address only
    lgdt cs:[eax]
    xor ebx,ebx                  ; initialize data selectors
    mov bl,data_selc             ; GDT[3]
    mov ds,bx
    mov ss,bx
    mov es,bx
    mov fs,bx
    mov gs,bx
    jmp pejump
next:
    xor ebx,ebx                  ; initialize data selectors
    mov bl,data_selc             ; GDT[3]
    mov ds,bx
    mov ss,bx
    mov es,bx
    mov fs,bx
    mov gs,bx
    db 66h                       ; for the 80386, need to make a 32-bit jump
pejump:
    jmp far ptr c_startup        ; but the 80376 is already 32-bit.

    org 70h                      ; only if segment base is at 0ffffff80h
    jmp short start
INIT_CODE ENDS
END
```

This code should be linked into your application for boot loadable code. The following build file illustrates how this is accomplished.

```
FLAT; -- build program id
SEGMENT
    *segments (dpl=0),                  -- Give all user segments a DPL of 0.
    _phantom_code_ (dpl=0),             -- These two segments are created by
    _phantom_data_ (dpl=0),             -- the builder when the FLAT control is used.
    init_code  (base=0ffffff80h) ; -- Put startup code at the reset vector area.
GATE
    gl3 (entry=13, dpl=0, trap),        -- trap gate disables interrupts
    i32 (entry=32, dpl=0, interrupt),   -- interrupt gates doesn't

TABLE
    -- create GDT
    GDT (LOCATION = GDT_DESC,           -- In a buffer starting at GDT_DESC,
                                        -- BLD386 places the GDT base and
                                        -- GDT limit values. Buffer must be
                                        -- 6 bytes long. The base and limit
                                        -- values are places in this buffer
                                        -- as two bytes of limit plus
                                        -- four bytes of base in the format
                                        -- required for use by the LGDT
                                        -- instruction.
        ENTRY = (3:_phantom_code_,      -- Explicitly place segment
                 4:_phantom_data_,      -- entries into the GDT.
                 5:code32,
                 6:data,
                 7:init_code)
        ) ;
TASK
    MAIN_TASK
        (
         DPL  = 0,                      -- Task privilege level is 0.
         DATA = DATA,                   -- Points to a segment that
                                        -- indicates initial DS value.
         CODE = main,                   -- Entry point is main, which
                                        -- must be a public id.

         STACKS = (DATA),               -- Segment id points to stack
                                        -- segment. Sets the initial SS:ESP.
         NO INTENABLED,                 -- Disable interrupts.
         PRESENT                        -- Present bit in TSS set to 1.
        ) ;
    MEMORY
        (RANGE = (EPROM = ROM(0ffff8000h..0ffffffffh),
                  DRAM = RAM(0..0ffffh)),
        ALLOCATE = (EPROM = (MAIN_TASK))) ;

END
```

```
asm386 flatsim.a38 debug
asm386 application.a38 debug
bnd386 application.obj,flatsim.obj nolo debug oj (application.bnd)
bld386 application.bnd bf (flatsim.bld) bl flat
```

Commands to assemble and build a boot-loadable application named "application.a38". The initialization code is called "flatsim.a38", and build file is called "application.bld".

2.10 Self-Test

The 80376 has the capability to perform a self-test. The self-test checks the function of all of the Control ROM and most of the non-random logic of the part. Approximately one-half of the 80376 can be tested during self-test.

Self-Test is initiated on the 80376 when the RESET pin transitions from HIGH to LOW, and the $\overline{BUSY}$ pin is LOW. The self-test takes about 2^{20} clocks, or approximately 33 ms with a 16 MHz 80376 processor. At the completion of self-test the processor performs reset and begins normal operation. The part has successfully passed self-test if the contents of the EAX register is zero. If the EAX register is not zero then the self-test has detected a flaw in the part. If self-test is not selected after reset, EAX may be non-zero after reset.

2.11 Debugging Support

The 80376 provides several features which simplify the debugging process. The three categories of on-chip debugging aids are:

1. The code execution breakpoint opcode (0CCH).
2. The single-step capability provided by the TF bit in the flag register, and
3. The code and data breakpoint capability provided by the Debug Registers DR0–3, DR6, and DR7.

BREAKPOINT INSTRUCTION

A single-byte software interrupt (Int 3) breakpoint instruction is available for use by software debuggers. The breakpoint opcode is 0CCh, and generates an exception 3 trap when executed.

DEBUG REGISTERS

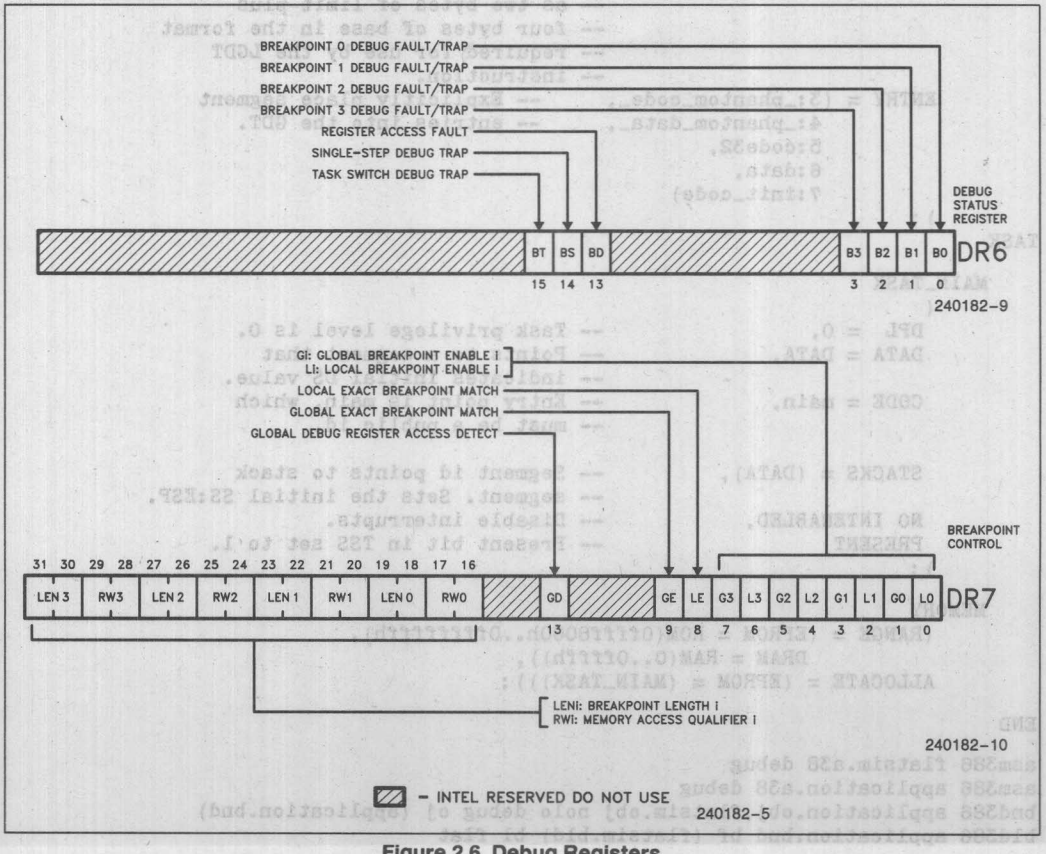


Figure 2.6. Debug Registers

SINGLE-STEP TRAP

If the single-step flag (TF, bit 8) in the EFLAG register is found to be set at the end of an instruction, a single-step exception occurs. The single-step exception is auto vectored to exception number 1.

The Debug Registers are an advanced debugging feature of the 80376. They allow data access breakpoints as well as code execution breakpoints. Since the breakpoints are indicated by on-chip registers, an instruction execution breakpoint can be placed in ROM code or in code shared by several tasks, neither of which can be supported by the INT 3 breakpoint opcode.

The 80376 contains six Debug Registers, consisting of four breakpoint address registers and two breakpoint control registers. Initially after reset, breakpoints are in the disabled state; therefore, no breakpoints will occur unless the debug registers are programmed. Breakpoints set up in the Debug Registers are auto-vectored to exception 1. Figure 2.6 shows the breakpoint status and control registers.

3.0 ARCHITECTURE

The Intel 80376 Embedded Processor has a physical address space of 16 Mbytes (2^{24} bytes) and allows the running of virtual memory programs of almost unlimited size (16 Kbytes × 16 Mbytes or 256 Gbytes (2^{38} bytes)). In addition the 80376 provides a sophisticated memory management and a hardware-assisted protection mechanism.

3.1 Addressing Mechanism

The 80376 uses two components to form the logical address, a 16-bit selector which determines the linear base address of a segment, and a 32-bit effective address. The selector is used to specify an index into an operating system defined table (see Figure 3.1). The table contains the 32-bit base address of a given segment. The linear address is formed by adding the base address obtained from the table to the 32-bit effective address. This value is truncated to 24 bits to form the physical address, which is then placed on the address bus.

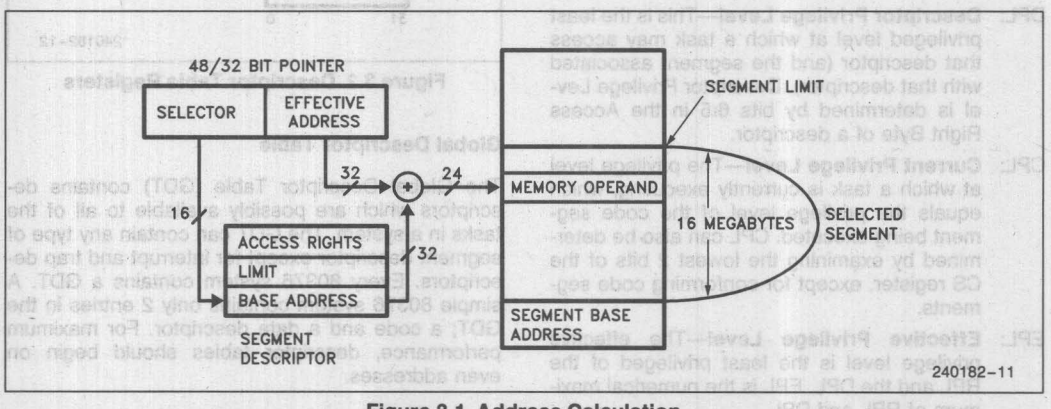


Figure 3.1. Address Calculation

3.2 Segmentation

Segmentation is one method of memory management and provides the basis for protection in the 80376. Segments are used to encapsulate regions of memory which have common attributes. For example, all of the code of a given program could be contained in a segment, or an operating system table may reside in a segment. All information about each segment, is stored in an 8-byte data structure called a descriptor. All of the descriptors in a system are contained in tables recognized by hardware.

TERMINOLOGY

The following terms are used throughout the discussion of descriptors, privilege levels and protection:

PL: **Privilege Level**—One of the four hierarchical privilege levels. Level 0 is the most privileged level and level 3 is the least privileged.

RPL: **Requestor Privilege Level**—The privilege level of the original supplier of the selector. RPL is determined by the least two significant bits of a selector.

DPL: **Descriptor Privilege Level**—This is the least privileged level at which a task may access that descriptor (and the segment associated with that descriptor). Descriptor Privilege Level is determined by bits 6:5 in the Access Right Byte of a descriptor.

CPL: **Current Privilege Level**—The privilege level at which a task is currently executing, which equals the privilege level of the code segment being executed. CPL can also be determined by examining the lowest 2 bits of the CS register, except for conforming code segments.

EPL: **Effective Privilege Level**—The effective privilege level is the least privileged of the RPL and the DPL. EPL is the numerical maximum of RPL and DPL.

Task: One instance of the execution of a program. Tasks are also referred to as processes.

DESCRIPTOR TABLES

The descriptor tables define all of the segments which are used in an 80376 system. There are three types of tables on the 80376 which hold descriptors: the Global Descriptor Table, Local Descriptor Table, and the Interrupt Decriptor Table. All of the tables are variable length memory arrays, they can range in size between 8 bytes and 64 Kbytes. Each table can hold up to 8192 8-byte descriptors. The upper 13 bits of a selector are used as an index into the descriptor table. The tables have registers associated with them which hold the 32-bit linear base address, and the 16-bit limit of each table.

Each of the tables have a register associated with it: GDTR, LDTR and IDTR; see Figure 3.2. The LGDT, LLDT and LIDT instructions load the base and limit of the Global, Local and Interrupt Descriptor Tables into the appropriate register. The SGDT, SLDT and SIDT store these base and limit values. These are privileged instructions.

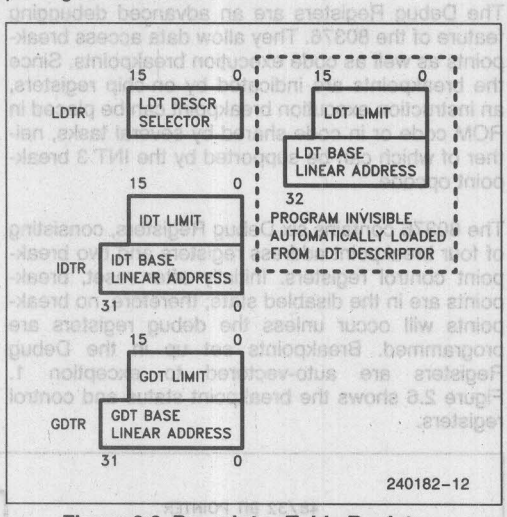


Figure 3.2. Descriptor Table Registers

Global Descriptor Table

The Global Descriptor Table (GDT) contains descriptors which are possibly available to all of the tasks in a system. The GDT can contain any type of segment descriptor except for interrupt and trap descriptors. Every 80376 system contains a GDT. A simple 80376 system contains only 2 entries in the GDT; a code and a data descriptor. For maximum performance, descriptor tables should begin on even addresses.

The first slot of the Global Descriptor Table corresponds to the null selector and is not used. The null selector defines a null pointer value.

Local Descriptor Table

LDTs contain descriptors which are associated with a given task. Generally, operating systems are designed so that each task has a separate LDT. The LDT may contain only code, data, stack, task gate, and call gate descriptors. LDTs provide a mechanism for isolating a given task's code and data segments from the rest of the operating system, while the GDT contains descriptors for segments which are common to all tasks. A segment cannot be accessed by a task if its segment descriptor does not exist in either the current LDT or the GDT. This pro-

vides both isolation and protection for a task's segments, while still allowing global data to be shared among tasks.

Unlike the 6-byte GDT or IDT registers which contain a base address and limit, the visible portion of the LDT register contains only a 16-bit selector. This selector refers to a Local Descriptor Table descriptor in the GDT (see Figure 2.1).

INTERRUPT DESCRIPTOR TABLE

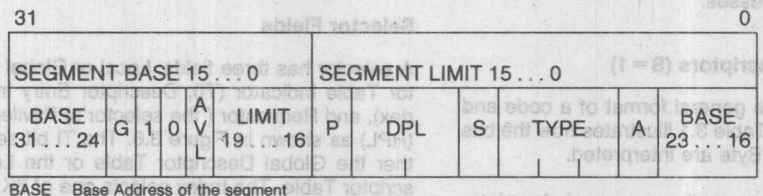
The third table needed for 80376 systems is the Interrupt Descriptor Table. The IDT contains the descriptors which point to the location of up to 256 interrupt service routines. The IDT may contain only task gates, interrupt gates and trap gates. The IDT should be at least 256 bytes in size in order to hold the descriptors for the 32 Intel Reserved Interrupts. Every interrupt used by a system must have an entry in the IDT. The IDT entries are referenced by INT instructions, external interrupt vectors, and exceptions.

DESCRIPTORS

The object to which the segment selector points to is called a descriptor. Descriptors are eight-byte quantities which contain attributes about a given region of linear address space. These attributes include the 32-bit logical base address of the segment, the 20-bit length and granularity of the segment, the protection level, read, write or execute privileges, and the type of segment. All of the attribute information about a segment is contained in 12 bits in the segment descriptor. Figure 3.3 shows the general format of a descriptor. All segments on the the 80376 have three attribute fields in common: the Present bit (P), the Descriptor Privilege Level bits (DPL) and the Segment bit (S). P = 1 if the segment is loaded in physical memory, if P = 0 then any attempt to access the segment causes a not present exception (exception 11). The DPL is a two-bit field which specifies the protection level, 0–3, associated with a segment.

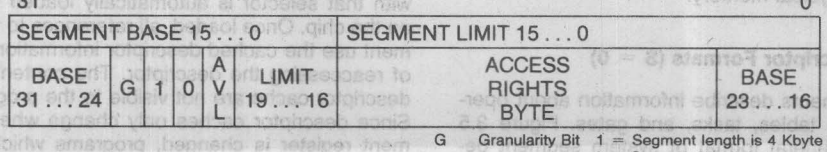
The 80376 has two main categories of segments: system segments, and non-system segments (for code and data). The segment bit, S, determines if a given segment is a system segment, a code segment or a data segment. If the S bit is 1 then the segment is either a code or data segment, if it is 0 then the segment is a system segment.

Note that although the 80376 is limited to a 16-Mbyte Physical address space (2^{24}), its base address allows a segment to be placed anywhere in a 4-Gbyte linear address space. When writing code for the 80376, users should keep code portability to an 80386 processor (or other processors with a larger physical address space) in mind. A segment base address can be placed anywhere in this 4-Gbyte linear address space, but a physical address will be



BASE Base Address of the segment
LIMIT The length of the segment
P Present Bit 1 = Present 0 = Not Present
DPL Descriptor Privilege Level 0–3
S Segment Descriptor: 0 = System Descriptor, 1 = Code or Data Descriptor
TYPE Type of Segment
A Accessed Bit
G Granularity Bit 1 = Segment length is 4 Kbyte Granular
0 = Segment length is byte granular
0 Bit must be zero (0) for compatibility with future processors
AVL Available field for user or OS

Figure 3.3. Segment Descriptors



G Granularity Bit 1 = Segment length is 4 Kbyte granular
0 = Segment length is byte granular
0 Bit must be zero (0) for compatibility with future processors
AVL Available field for user or OS

Figure 3.4. Code and Data Descriptors

Table 3.1. Access Rights Byte Definition for Code and Data Descriptors

Bit Position	Name	Function	
7	Present (P)	P = 1 Segment is mapped into physical memory. P = 0 No mapping to physical memory exits	
6–5	Descriptor Privilege Level (DPL)	Segment privilege attribute used in privilege tests.	
4	Segment Descriptor (S)	S = 1 Code or Data (includes stacks) segment descriptor S = 0 System Segment Descriptor or Gate Descriptor	
3	Executable (E)	E = 0 Descriptor type is data segment:	If Data Segment (S = 1, E = 0)
2	Expansion Direction (ED)	ED = 0 Expand up segment, offsets must be ≤ limit. ED = 1 Expand down segment, offsets must be > limit.	
1	Writable (W)	W = 0 Data segment may not be written into. W = 1 Data segment may be written into.	
3	Executable (E)	E = 1 Descriptor type is code segment:	If Code Segment (S = 1, E = 1)
2	Conforming (C)	C = 1 Code segment may only be executed when CPL ≥ DPL and CPL remains unchanged.	
1	Readable (R)	R = 0 Code segment may not be read. R = 1 Code segment may be read.	
0	Accessed (A)	A = 0 Segment has not been accessed. A = 1 Segment selector has been loaded into segment register or used by selector test instructions.	

generated that is a truncated version of this linear address. Truncation will be to the maximum number of address bits. It is recommended to place EPROM at the highest physical address and DRAM at the lowest physical addresses.

Code and Data Descriptors (S = 1)

Figure 3.4 shows the general format of a code and data descriptor and Table 3.1 illustrates how the bits in the Access Right Byte are interpreted.

Code and data segments have several descriptor fields in common. The accessed bit, A, is set whenever the processor accesses a descriptor. The granularity bit, G, specifies if a segment length is 1-byte-granular or 4-Kbyte-granular. Base address bits 31–24, which are normally found in 80386 descriptors, are not made externally available on the 80376. They do not affect the operation of the 80376. The A_{31}–A_{24} field should be set to allow an 80386 to correctly execute with EPROM at the upper 4096 Mbytes of physical memory.

System Descriptor Formats (S = 0)

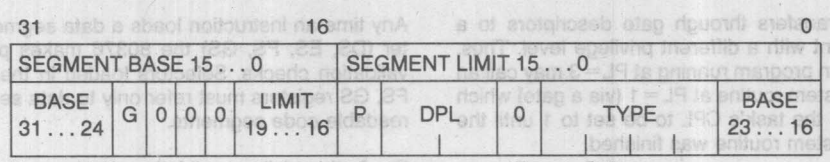
System segments describe information about operating system tables, tasks, and gates. Figure 3.5 shows the general format of system segment descriptors, and the various types of system segments. 80376 system descriptors (which are the same as 80386 descriptor types 2, 5, 9, B, C, E and F) contain a 32-bit logical base address and a 20-bit segment limit.

Selector Fields

A selector has three fields: Local or Global Descriptor Table Indicator (TI), Descriptor Entry Index (Index), and Requestor (the selector's) Privilege Level (RPL) as shown in Figure 3.6. The TI bit selects either the Global Descriptor Table or the Local Descriptor Table. The Index selects one of 8K descriptors in the appropriate descriptor table. The RPL bits allow high speed testing of the selector's privilege attributes.

Segment Descriptor Cache

In addition to the selector value, every segment register has a segment descriptor cache register associated with it. Whenever a segment register's contents are changed, the 8-byte descriptor associated with that selector is automatically loaded (cached) on the chip. Once loaded, all references to that segment use the cached descriptor information instead of reaccessing the descriptor. The contents of the descriptor cache are not visible to the programmer. Since descriptor caches only change when a segment register is changed, programs which modify the descriptor tables must reload the appropriate segment registers after changing a descriptor's value.



Type	Defines
0	Invalid
1	Reserved
2	LDT
3	Reserved
4	Reserved
5	Task Gate (80376/80386 Task)
6	Reserved
7	Reserved

Type	Defines
8	Invalid
9	Available 80376/80386 TSS
A	Undefined (Intel Reserved)
B	Busy 80376/80386 TSS
C	80376/80386 Call Gate
D	Undefined (Intel Reserved)
E	80376/80386 Interrupt Gate
F	80376/80386 Trap Gate

Figure 3.5. System Descriptors

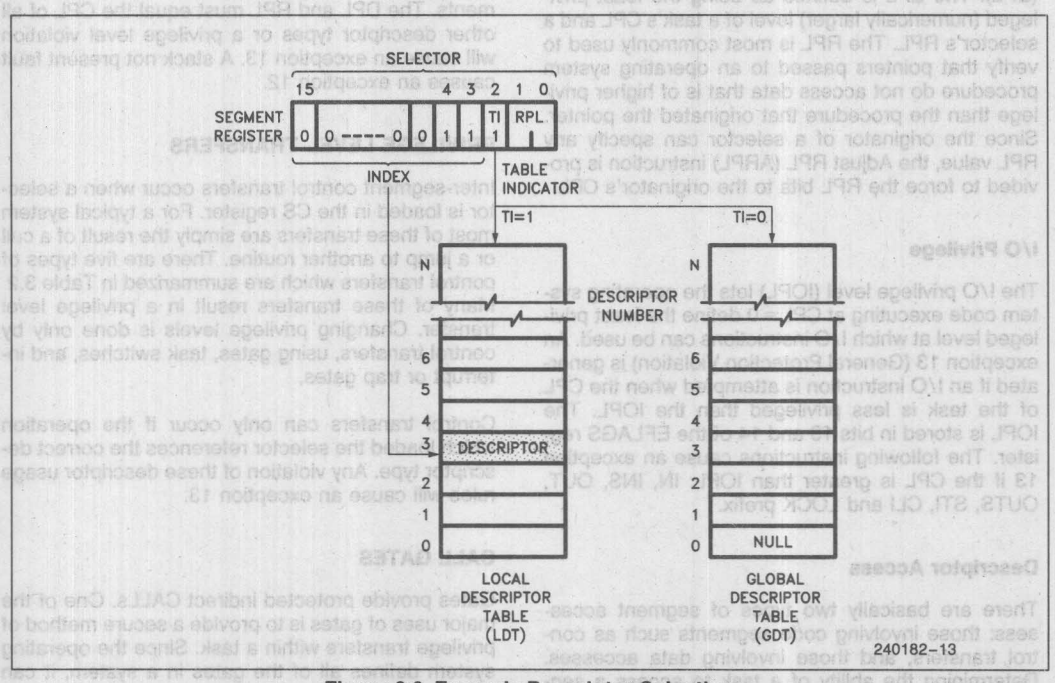


Figure 3.6. Example Descriptor Selection

3.3 Protection

The 80376 offers extensive protection features. These protection features are particularly useful in sophisticated embedded applications which use multitasking real-time operating systems. For simpler embedded applications these protection capabilities can be easily bypassed by making all applications run at privilege level (PL) 0.

RULES OF PRIVILEGE

The 80376 controls access to both data and procedures between levels of a task, according to the following rules.

—Data stored in a segment with privilege level **p** can be accessed only by code executing at a privilege level at least as privileged as **p.**

—A code segment/procedure with privilege level **p** can only be called by a task executing at the same or a lesser privilege level than **p.**

PRIVILEGE LEVELS

At any point in time, a task on the 80376 always executes at one of the four privilege levels. The Current Privilege Level (CPL) specifies what the task's privilege level is. A task's CPL may only be changed

9

by control transfers through gate descriptors to a code segment with a different privilege level. Thus, an application program running at PL = 3 may call an operating system routine at PL = 1 (via a gate) which would cause the task's CPL to be set to 1 until the operating system routine was finished.

Selector Privilege (RPL)

The privilege level of a selector is specified by the RPL field. The selector's RPL is only used to establish a less trusted privilege level than the current privilege level of the task for the use of a segment. This level is called the task's effective privilege level (EPL). The EPL is defined as being the least privileged (numerically larger) level of a task's CPL and a selector's RPL. The RPL is most commonly used to verify that pointers passed to an operating system procedure do not access data that is of higher privilege than the procedure that originated the pointer. Since the originator of a selector can specify any RPL value, the Adjust RPL (ARPL) instruction is provided to force the RPL bits to the originator's CPL.

I/O Privilege

The I/O privilege level (IOPL) lets the operating system code executing at CPL = 0 define the least privileged level at which I/O instructions can be used. An exception 13 (General Protection Violation) is generated if an I/O instruction is attempted when the CPL of the task is less privileged than the IOPL. The IOPL is stored in bits 13 and 14 of the EFLAGS register. The following instructions cause an exception 13 if the CPL is greater than IOPL: IN, INS, OUT, OUTS, STI, CLI and LOCK prefix.

Descriptor Access

There are basically two types of segment accesses: those involving code segments such as control transfers, and those involving data accesses. Determining the ability of a task to access a segment involves the type of segment to be accessed, the instruction used, the type of descriptor used and CPL, RPL, and DPL as described above.

Any time an instruction loads a data segment register (DS, ES, FS, GS) the 80376 makes protection validation checks. Selectors loaded in the DS, ES, FS, GS registers must refer only to data segment or readable code segments.

Finally the privilege validation checks are performed. The CPL is compared to the EPL and if the EPL is more privileged than the CPL, an exception 13 (general protection fault) is generated.

The rules regarding the stack segment are slightly different than those involving data segments. Instructions that load selectors into SS must refer to data segment descriptors for writeable data segments. The DPL and RPL must equal the CPL of all other descriptor types or a privilege level violation will cause an exception 13. A stack not present fault causes an exception 12.

PRIVILEGE LEVEL TRANSFERS

Inter-segment control transfers occur when a selector is loaded in the CS register. For a typical system most of these transfers are simply the result of a call or a jump to another routine. There are five types of control transfers which are summarized in Table 3.2 Many of these transfers result in a privilege level transfer. Changing privilege levels is done only by control transfers, using gates, task switches, and interrupt or trap gates.

Control transfers can only occur if the operation which loaded the selector references the correct descriptor type. Any violation of these descriptor usage rules will cause an exception 13.

CALL GATES

Gates provide protected indirect CALLs. One of the major uses of gates is to provide a secure method of privilege transfers within a task. Since the operating system defines all of the gates in a system, it can ensure that all gates only allow entry into a few trusted procedures.

Table 3.2. Descriptor Types Used for Control Transfer

Control Transfer Types	Operation Types	Descriptor Referenced	Descriptor Table
Intersegment within the same privilege level	JMP, CALL, RET, IRET*	Code Segment	GDT/LDT
Intersegment to the same or higher privilege level Interrupt within task may change CPL	CALL	Call Gate	GDT/LDT
	Interrupt Instruction, Exception, External Interrupt	Trap or Interrupt Gate	IDT
Intersegment to a lower privilege level (changes task CPL)	RET, IRET*	Code Segment	GDT/LDT
	CALL, JMP	Task State Segment	GDT
Task Switch	CALL, JMP	Task Gate	GDT/LDT
	IRET** Interrupt Instruction, Exception, External Interrupt	Task Gate	IDT

*NT (Nested Task bit of flag register) = 0
**NT (Nested Task bit of flag register) = 1

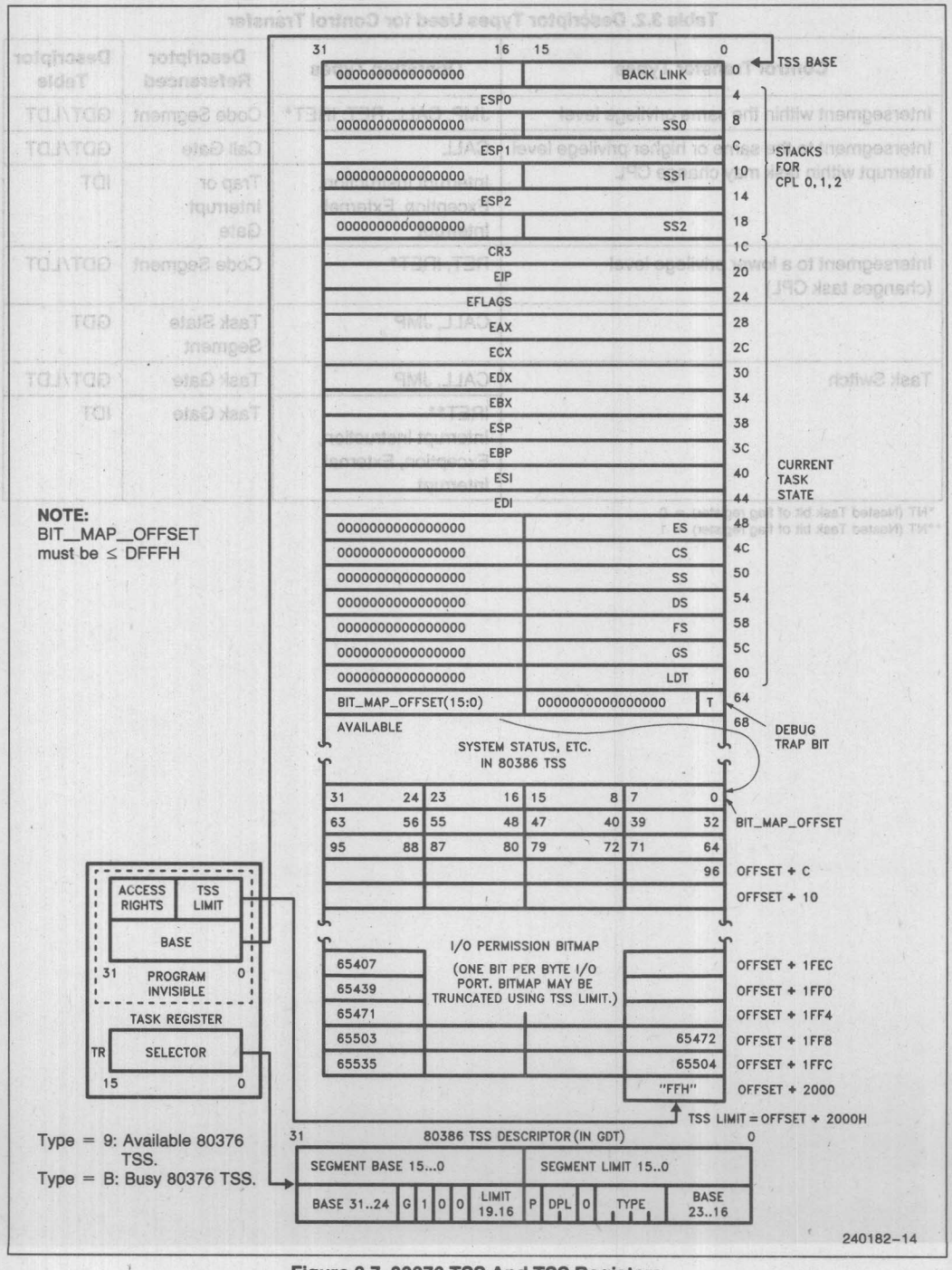


Figure 3.7. 80376 TSS And TSS Registers

TASK SWITCHING

A very important attribute of any multi-tasking operating system is its ability to rapidly switch between tasks or processes. The 80376 directly supports this operation by providing a task switch instruction in hardware. The 80376 task switch operation saves the entire state of the machine (all of the registers, address space, and a link to the previous task), loads a new execution state, performs protection checks, and commences execution in the new task. Like transfer of control by gates, the task switch operation is invoked by executing an inter-segment JMP or CALL instruction which refers to a Task State Segment (TSS), or a task gate descriptor in the GDT or LDT. An INT n instruction, exception, trap or external interrupt may also invoke the task switch operation if there is a task gate descriptor in the associated IDT descriptor slot. For simple applications, the TSS and task switching may not be used. The TSS or task switch will not be used or occur if no task gates are present in the GDT, LDT or IDT.

The TSS descriptor points to a segment (see Figure 3.7) containing the entire 80376 execution state. A task gate descriptor contains a TSS selector. The limit of an 80376 TSS must be greater than 64H, and can be as large as 16 Mbytes. In the additional TSS space, the operating system is free to store additional information as the reason the task is inactive, the time the task has spent running, and open files belonging to the task. For maximum performance, TSS should start on an even address.

Each Task must have a TSS associated with it. The current TSS is identified by a special register in the 80376 called the Task State Segment Register (TR). This register contains a selector referring to the task state segment descriptor that defines the current TSS. A hidden base and limit register associated with the TSS descriptor is loaded whenever TR is loaded with a new selector. Returning from a task is accomplished by the IRET instruction. When IRET is executed, control is returned to the task which was interrupted. The current executing task's state is saved in the TSS and the old task state is restored from its TSS.

Several bits in the flag register and CR0 register give information about the state of a task which is useful to the operating system. The Nested Task bit, NT, controls the function of the IRET instruction. If NT = 0 the IRET instruction performs the regular return. If NT = 1, IRET performs a task switch operation back to the previous task. The NT bit is set or reset in the following fashion:

When a CALL or INT instruction initiates a task switch, the new TSS will be marked busy and the back link field of the new TSS set to the old TSS selector. The NT bit of the new task is set by CALL or INT initiated task switches. An interrupt that does not cause a task switch will clear NT (The NT bit will be restored after execution of the interrupt handler). NT may also be set or cleared by POPF or IRET instructions.

The 80376 task state segment is marked busy by changing the descriptor type field from TYPE 9 to TYPE 0BH. Use of a selector that references a busy task state segment causes an exception 13.

The coprocessor's state is not automatically saved when a task switch occurs. The Task Switched Bit, TS, in the CR0 register helps deal with the coprocessor's state in a multi-tasking environment. Whenever the 80376 switches tasks, it sets the TS bit. The 80376 detects the first use of a processor extension instruction after a task switch and causes the processor extension not available exception 7. The exception handler for exception 7 may then decide whether to save the state of the coprocessor.

The T bit in the 80376 TSS indicates that the processor should generate a debug exception when switching to a task. If T = 1 then upon entry to a new task a debug exception 1 will be generated.

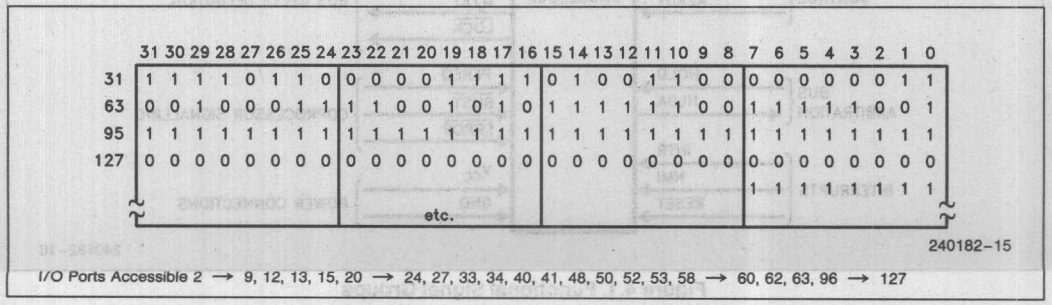


Figure 3.8. Sample I/O Permission Bit Map

PROTECTION AND I/O PERMISSION BIT MAP

The I/O instructions that directly refer to addresses in the processor's I/O space are IN, INS, OUT and OUTS. The 80376 has the ability to selectively trap references to specific I/O addresses. The structure that enables selective trapping is the ***I/O Permission Bit Map*** in the TSS segment (see Figures 3.7 and 3.8). The I/O permission map is a bit vector. The size of the map and its location in the TSS segment are variable. The processor locates the I/O permission map by means of the **I/O map base** field in the fixed portion of the TSS. The **I/O map base** field is 16 bits wide and contains the offset of the beginning of the I/O permission map.

If an I/O instruction (IN, INS, OUT or OUTS) is encountered, the processor first checks whether CPL ≤ IOPL. If this condition is true, the I/O operation may proceed. If not true, the processor checks the I/O permission map.

Each bit in the map corresponds to an I/O port byte address; for example, the bit for port 41 is found at **I/O map base** + 5 linearly, (5 × 8 = 40), bit offset 1. The processor tests all the bits that correspond to the I/O addresses spanned by an I/O operation; for example, a double word operation tests four bits corresponding to four adjacent byte addresses. If any tested bit is set, the processor signals a general protection exception. If all the tested bits are zero, the I/O operations may proceed.

It is not necessary for the I/O permission map to represent all the I/O addresses. I/O addresses not spanned by the map are treated as if they had one-bits in the map. The **I/O map base** should be at least one byte less than the TSS limit and the last byte beyond the I/O mapping information must contain all 1's.

Because the I/O permission map is in the TSS segment, different tasks can have different maps. Thus, the operating system can allocate ports to a task by changing the I/O permission map in the task's TSS.

IMPORTANT IMPLEMENTATION NOTE:
Beyond the last byte of I/O mapping information in the I/O permission bit map **must** be a byte containing all 1's. The byte of all 1's must be within the limit of the 80376's TSS segment (see Figure 3.7).

4.0 FUNCTIONAL DATA

The Intel 80376 embedded processor features a straightforward functional interface to the external hardware. The 80376 has separate parallel buses for data and address. The data bus is 16 bits in width, and bidirectional. The address bus outputs 24-bit address values using 23 address lines and two-byte enable signals.

The 80376 has two selectable address bus cycles: pipelined and non-pipelined. The pipelining option allows as much time as possible for data access by

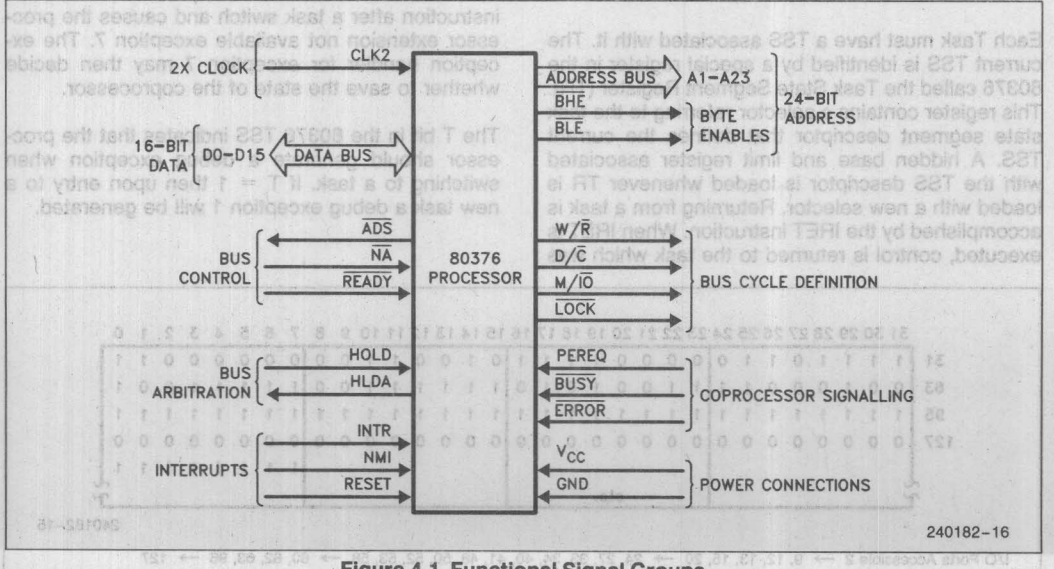


Figure 4.1. Functional Signal Groups

starting the pending bus cycle before the present bus cycle is finished. A non-pipelined bus cycle gives the highest bus performance by executing every bus cycle in two processor clock cycles. For maximum design flexibility, the address pipelining option is selectable on a cycle-by-cycle basis.

The processor's bus cycle is the basic mechanism for information transfer, either from system to processor, or from processor to system. 80376 bus cycles perform data transfer in a minimum of only two clock periods. On a 16-bit data bus, the maximum 80376 transfer bandwidth at 16 MHz is therefore 16 Mbytes/sec. However, any bus cycle will be extended for more than two clock periods if external hardware withholds acknowledgement of the cycle.

The 80376 can relinquish control of its local buses to allow mastership by other devices, such as direct memory access (DMA) channels. When relinquished, HLDA is the only output pin driven by the 80376, providing near-complete isolation of the processor from its system (all other output pins are in a float condition).

4.1 Signal Description Overview

Ahead is a brief description of the 80376 input and output signals arranged by functional groups.

The signal descriptions sometimes refer to A.C. timing parameters, such as "t_{25} Reset Setup Time" and "t_{26} Reset Hold Time." The values of these parameters can be found in Tables 6.4 and 6.5.

CLOCK (CLK2)

CLK2 provides the fundamental timing for the 80376. It is divided by two internally to generate the internal processor clock used for instruction execution. The internal clock is comprised of two

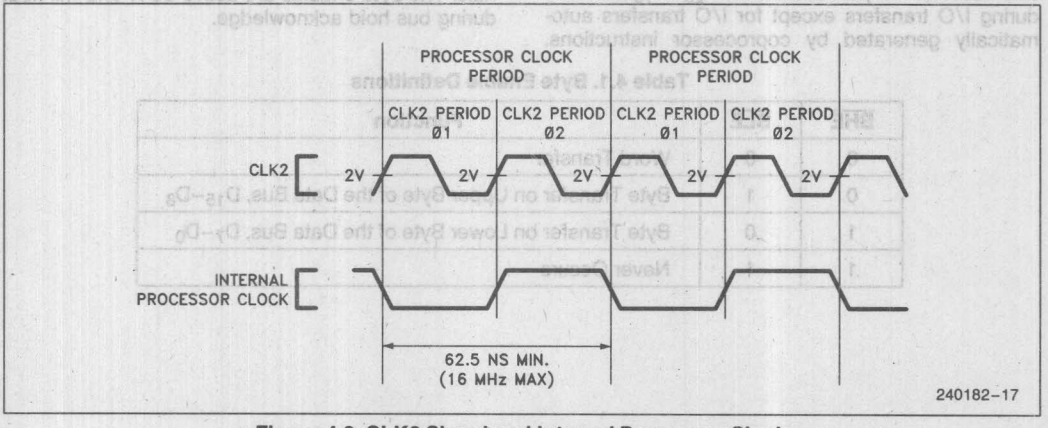


Figure 4.2. CLK2 Signal and Internal Processor Clock

9

phases, "phase one" and "phase two". Each CLK2 period is a phase of the internal clock. Figure 4.2 illustrates the relationship. If desired, the phase of the internal processor clock can be synchronized to a known phase by ensuring the falling edge of the RESET signal meets the applicable setup and hold times t_{25} and t_{26}.

DATA BUS (D_{15}–D_0)

These three-state bidirectional signals provide the general purpose data path between the 80376 and other devices. The data bus outputs are active HIGH and will float during bus hold acknowledge. Data bus reads require that read-data setup and hold times t_{21} and t_{22} be met relative to CLK2 for correct operation.

ADDRESS BUS ($\overline{BHE}$, $\overline{BLE}$, A_{23}–A_1)

These three-state outputs provide physical memory addresses or I/O port addresses. A_{23}–A_{16} are LOW during I/O transfers except for I/O transfers automatically generated by coprocessor instructions. During coprocessor I/O transfers, A_{22}–A_{16} are driven LOW, and A_{23} is driven HIGH so that this address line can be used by external logic to generate the coprocessor select signal. Thus, the I/O address driven by the 80376 for coprocessor commands is 8000F8H, and the I/O address driven by the 80376 processor for coprocessor data is 8000FCH or 8000FEH.

The address bus is capable of addressing 16 Mbytes of physical memory space (000000H through 0FFFFFFH), and 64 Kbytes of I/O address space (000000H through 00FFFFH) for programmed I/O. The address bus is active HIGH and will float during bus hold acknowledge.

The Byte Enable outputs $\overline{BHE}$ and $\overline{BLE}$ directly indicate which bytes of the 16-bit data bus are involved with the current transfer. $\overline{BHE}$ applies to D_{15}–D_8 and $\overline{BLE}$ applies to D_7–D_0. If both $\overline{BHE}$ and $\overline{BLE}$ are asserted, then 16 bits of data are being transferred. See Table 4.1 for a complete decoding of these signals. The byte enables are active LOW and will float during bus hold acknowledge.

Table 4.1. Byte Enable Definitions

$\overline{BHE}$	$\overline{BLE}$	Function
0	0	Word Transfer
0	1	Byte Transfer on Upper Byte of the Data Bus, D_{15}–D_8
1	0	Byte Transfer on Lower Byte of the Data Bus, D_7–D_0
1	1	Never Occurs

BUS CYCLE DEFINITION SIGNALS (W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{LOCK}$)

These three-state outputs define the type of bus cycle being performed: W/$\overline{R}$ distinguishes between write and read cycles, D/$\overline{C}$ distinguishes between data and control cycles, M/$\overline{IO}$ distinguishes between memory and I/O cycles, and $\overline{LOCK}$ distinguishes between locked and unlocked bus cycles. All of these signals are active LOW and will float during bus acknowledge.

The primary bus cycle definition signals are W/$\overline{R}$, D/$\overline{C}$ and M/$\overline{IO}$, since these are the signals driven valid as $\overline{ADS}$ (Address Status output) becomes active. The $\overline{LOCK}$ signal is driven valid at the same time the bus cycle begins, which due to address pipelining, could be after $\overline{ADS}$ becomes active. Exact bus cycle definitions, as a function of W/$\overline{R}$, D/$\overline{C}$ and M/$\overline{IO}$ are given in Table 4.2.

$\overline{LOCK}$ indicates that other system bus masters are not to gain control of the system bus while it is active. $\overline{LOCK}$ is activated on the CLK2 edge that begins the first locked bus cycle (i.e., it is not active at the same time as the other bus cycle definition pins) and is deactivated when ready is returned to the end of the last bus cycle which is to be locked. The beginning of a bus cycle is determined when $\overline{READY}$ is returned in a previous bus cycle and another is pending ($\overline{ADS}$ is active) or the clock in which $\overline{ADS}$ is driven active if the bus was idle. This means that it follows more closely with the write data rules when it is valid, but may cause the bus to be locked longer than desired. The $\overline{LOCK}$ signal may be explicitly activated by the LOCK prefix on certain instructions. $\overline{LOCK}$ is always asserted when executing the XCHG instruction, during descriptor updates, and during the interrupt acknowledge sequence.

BUS CONTROL SIGNALS ($\overline{ADS}$, $\overline{READY}$, $\overline{NA}$)

The following signals allow the processor to indicate when a bus cycle has begun, and allow other system hardware to control address pipelining and bus cycle termination.

Address Status ($\overline{ADS}$)

This three-state output indicates that a valid bus cycle definition and address (W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{BHE}$, $\overline{BLE}$ and A_{23}–A_1) are being driven at the 80376 pins. $\overline{ADS}$ is an active LOW output. Once $\overline{ADS}$ is driven active, valid address, byte enables, and definition signals will not change. In addition, $\overline{ADS}$ will remain active until its associated bus cycle begins (when $\overline{READY}$ is returned for the previous bus cycle when running pipelined bus cycles). $\overline{ADS}$ will float during bus hold acknowledge. See sections **Non-Pipelined Bus Cycles** and **Pipelined Bus Cycles** for additional information on how $\overline{ADS}$ is asserted for different bus states.

Transfer Acknowledge ($\overline{READY}$)

This input indicates the current bus cycle is complete, and the active bytes indicated by $\overline{BHE}$ and $\overline{BLE}$ are accepted or provided. When $\overline{READY}$ is sampled active during a read cycle or interrupt acknowledge cycle, the 80376 latches the input data and terminates the cycle. When $\overline{READY}$ is sampled active during a write cycle, the processor terminates the bus cycle.

Table 4.2. Bus Cycle Definition

M/$\overline{IO}$	D/$\overline{C}$	W/$\overline{R}$	Bus Cycle Type	Locked?
0	0	0	INTERRUPT ACKNOWLEDGE	Yes
0	0	1	Does Not Occur	—
0	1	0	I/O DATA READ	No
0	1	1	I/O DATA WRITE	No
1	0	0	MEMORY CODE READ	No
1	0	1	HALT: Address = 2, $\overline{BHE}$ = 1, $\overline{BLE}$ = 0 — SHUTDOWN: Address = 0, $\overline{BHE}$ = 1, $\overline{BLE}$ = 0	No
1	1	0	MEMORY DATA READ	Some Cycles
1	1	1	MEMORY DATA WRITE	Some Cycles

9

READY is ignored on the first bus state of all bus cycles, and sampled each bus state thereafter until asserted. READY must eventually be asserted to acknowledge every bus cycle, including Halt Indication and Shutdown Indication bus cycles. When being sampled, READY must always meet setup and hold times t_{19} and t_{20} for correct operation.

Next Address Request (NA)

This is used to request pipelining. This input indicates the system is prepared to accept new values of BHE, BLE, A_{23}–A_1, W/R, D/C and M/IO from the 80376 even if the end of the current cycle is not being acknowledged on READY. If this input is active when sampled, the next bus cycle's address and status signals are driven onto the bus, provided the next bus request is already pending internally. NA is ignored in clock cycles in which ADS or READY is activated. This signal is active LOW and must satisfy setup and hold times t_{15} and t_{16} for correct operation. See **Pipelined Bus Cycles** and **Read and Write Cycles** for additional information.

BUS ARBITRATION SIGNALS (HOLD, HLDA)

This section describes the mechanism by which the processor relinquishes control of its local buses when requested by another bus master device. See **Entering and Exiting Hold Acknowledge** for additional information.

Bus Hold Request (HOLD)

This input indicates some device other than the 80376 requires bus mastership. When control is granted, the 80376 floats A_{23}–A_1, BHE, BLE, D_{15}–D_0, LOCK, M/IO, D/C, W/R and ADS, and then activates HLDA, thus entering the bus hold acknowledge state. The local bus will remain granted to the requesting master until HOLD becomes inactive. When HOLD becomes inactive, the 80376 will deactivate HLDA and drive the local bus (at the same time), thus terminating the hold acknowledge condition.

HOLD must remain asserted as long as any other device is a local bus master. External pull-up resistors may be required when in the hold acknowledge state since none of the 80376 floated outputs have internal pull-up resistors. See **Resistor Recommendations** for additional information. HOLD is not recognized while RESET is active but is recognized during the time between the high-to-low transistion of RESET and the first instruction fetch. If RESET is asserted while HOLD is asserted, RESET has priority and places the bus into an idle state, rather than the hold acknowledge (high-impedance) state.

HOLD is a level-sensitive, active HIGH, synchronous input. HOLD signals must always meet setup and hold times t_{23} and t_{24} for correct operation.

Bus Hold Acknowledge (HLDA)

When active (HIGH), this output indicates the 80376 has relinquished control of its local bus in response to an asserted HOLD signal, and is in the bus Hold Acknowledge state.

The Bus Hold Acknowledge state offers near-complete signal isolation. In the Hold Acknowledge state, HLDA is the only signal being driven by the 80376. The other output signals or bidirectional signals (D_{15}–D_0, BHE, BLE, A_{23}–A_1, W/R, D/C, M/IO, LOCK and ADS) are in a high-impedance state so the requesting bus master may control them. These pins remain OFF throughout the time that HLDA remains active (see Table 4.3). Pull-up resistors may be desired on several signals to avoid spurious activity when no bus master is driving them. See **Resistor Recommendations** for additional information.

When the HOLD signal is made inactive, the 80376 will deactivate HLDA and drive the bus. One rising edge on the NMI input is remembered for processing after the HOLD input is negated.

Table 4.3. Output Pin State during HOLD

Pin Value	Pin Names
1	HLDA
Float	LOCK, M/IO, D/C, W/R, ADS, A_{23}–A_1, BHE, BLE, D_{15}–D_0

Hold Latencies

The maximum possible HOLD latency depends on the software being executed. The actual HOLD latency at any time depends on the current bus activity, the state of the LOCK signal (internal to the CPU) activated by the LOCK prefix, and interrupts. The 80376 will not honor a HOLD request until the current bus operation is complete.

The 80376 breaks 32-bit data or I/O accesses into 2 internally locked 16-bit bus cycles; the LOCK signal is not asserted. The 80376 breaks unaligned 16-bit or 32-bit data or I/O accesses into 2 or 3 internally locked 16-bit bus cycles. Again the LOCK signal is not asserted but a HOLD request will not be recognized until the end of the entire transfer.

Wait states affect HOLD latency. The 80376 will not honor a HOLD request until the end of the current bus operation, no matter how many wait states are required. Systems with DMA where data transfer is critical must insure that $\overline{\text{READY}}$ returns sufficiently soon.

COPROCESSOR INTERFACE SIGNALS (PEREQ, $\overline{\text{BUSY}}$, $\overline{\text{ERROR}}$)

In the following sections are descriptions of signals dedicated to the numeric coprocessor interface. In addition to the data bus, address bus, and bus cycle definition signals, these following signals control communication between the 80376 and the 80387SX processor extension.

Coprocessor Request (PEREQ)

When asserted (HIGH), this input signal indicates a coprocessor request for a data operand to be transferred to/from memory by the 80376. In response, the 80376 transfers information between the coprocessor and memory. Because the 80376 has internally stored the coprocessor opcode being executed, it performs the requested data transfer with the correct direction and memory address.

PEREQ is a level-sensitive active HIGH asynchronous signal. Setup and hold times, t_{29} and t_{30}, relative to the CLK2 signal must be met to guarantee recognition at a particular clock edge. This signal is provided with a weak internal pull-down resistor of around 20 KΩ to ground so that it will not float active when left unconnected.

Coprocessor Busy ($\overline{\text{BUSY}}$)

When asserted (LOW), this input indicates the coprocessor is still executing an instruction, and is not yet able to accept another. When the 80376 encounters any coprocessor instruction which operates on the numerics stack (e.g. load, pop, or arithmetic operation), or the WAIT instruction, this input is first automatically sampled until it is seen to be inactive. This sampling of the $\overline{\text{BUSY}}$ input prevents overrunning the execution of a previous coprocessor instruction.

The F(N)INIT, F(N)CLEX coprocessor instructions are allowed to execute even if $\overline{\text{BUSY}}$ is active, since these instructions are used for coprocessor initialization and exception-clearing.

$\overline{\text{BUSY}}$ is an active LOW, level-sensitive asynchronous signal. Setup and hold times, t_{29} and t_{30}, relative to the CLK2 signal must be met to guarantee recognition at a particular clock edge. This pin is provided with a weak internal pull-up resistor of around 20 KΩ to V_{CC} so that it will not float active when left unconnected.

$\overline{\text{BUSY}}$ serves an additional function. If $\overline{\text{BUSY}}$ is sampled LOW at the falling edge of RESET, the 80376 processor performs an internal self-test (see **Bus Activity During and Following Reset.** If $\overline{\text{BUSY}}$ is sampled HIGH, no self-test is performed.

Coprocessor Error ($\overline{\text{ERROR}}$)

When asserted (LOW), this input signal indicates that the previous coprocessor instruction generated a coprocessor error of a type not masked by the coprocessor's control register. This input is automatically sampled by the 80376 when a coprocessor instruction is encountered, and if active, the 80376 generates exception 16 to access the error-handling software.

Several coprocessor instructions, generally those which clear the numeric error flags in the coprocessor or save coprocessor state, do execute without the 80376 generating exception 16 even if $\overline{\text{ERROR}}$ is active. These instructions are FNINIT, FNCLEX, FNSTSW, FNSTSWAX, FNSTCW, FNSTENV and FNSAVE.

$\overline{\text{ERROR}}$ is an active LOW, level-sensitive asynchronous signal. Setup and hold times t_{29} and t_{30}, relative to the CLK2 signal must be met to guarantee recognition at a particular clock edge. This pin is provided with a weak internal pull-up resistor of around 20 KΩ to V_{CC} so that it will not float active when left unconnected.

INTERRUPT SIGNALS (INTR, NMI, RESET)

The following descriptions cover inputs that can interrupt or suspend execution of the processor's current instruction stream.

Maskable Interrupt Request (INTR)

When asserted, this input indicates a request for interrupt service, which can be masked by the 80376 Flag Register IF bit. When the 80376 responds to the INTR input, it performs two interrupt acknowledge bus cycles and, at the end of the second, latches an 8-bit interrupt vector on D_7-D_0 to identify the source of the interrupt.

INTR is an active HIGH, level-sensitive asynchronous signal. Setup and hold times, t_{27} and t_{28}, relative to the CLK2 signal must be met to guarantee recognition at a particular clock edge. To assure recognition of an INTR request, INTR should remain active until the first interrupt acknowledge bus cycle begins. INTR is sampled at the beginning of every instruction. In order to be recognized at a particular instruction boundary, INTR must be active at least eight CLK2 clock periods before the beginning of the execution of the instruction. If recognized, the 80376 will begin execution of the interrupt.

Non-Maskable Interrupt Request (NMI)

This input indicates a request for interrupt service which cannot be masked by software. The non-maskable interrupt request is always processed according to the pointer or gate in slot 2 of the interrupt table. Because of the fixed NMI slot assignment, no interrupt acknowledge cycles are performed when processing NMI.

NMI is an active HIGH, rising edge-sensitive asynchronous signal. Setup and hold times, t_{27} and t_{28}, relative to the CLK2 signal must be met to guarantee recognition at a particular clock edge. To assure recognition of NMI, it must be inactive for at least eight CLK2 periods, and then be active for at least eight CLK2 periods before the beginning of the execution of an instruction.

Once NMI processing has begun, no additional NMI's are processed until after the next IRET instruction, which is typically the end of the NMI service routine. If NMI is re-asserted prior to that time, however, one rising edge on NMI will be remembered for processing after executing the next IRET instruction.

Interrupt Latency

The time that elapses before an interrupt request is serviced (interrupt latency) varies according to several factors. This delay must be taken into account by the interrupt source. Any of the following factors can affect interrupt latency:

1. If interrupts are masked, and INTR request will not be recognized until interrupts are reenabled.
2. If an NMI is currently being serviced, an incoming NMI request will not be recognized until the 80376 encounters the IRET instruction.
3. An interrupt request is recognized only on an instruction boundary of the 80376 ***Execution Unit*** except for the following cases:
   - — Repeat string instructions can be interrupted after each iteration.
   - — If the instruction loads the Stack Segment register, an interrupt is not processed until after the following instruction, which should be an ESP load. This allows the entire stack pointer to be loaded without interruption.
   - — If an instruction sets the interrupt flag (enabling interrupts), an interrupt is not processed until after the next instruction.

   The longest latency occurs when the interrupt request arrives while the 80376 processor is executing a long instruction such as multiplication, division or a task-switch.
4. Saving the Flags register and CS:EIP registers.
5. If interrupt service routine requires a task switch, time must be allowed for the task switch.
6. If the interrupt service routine saves registers that are not automatically saved by the 80376.

RESET

This input signal suspends any operation in progress and places the 80376 in a known reset state. The 80376 is reset by asserting RESET for 15 or more CLK2 periods (80 or more CLK2 periods before requesting self-test). When RESET is active, all other input pins except $\overline{FLT}$ are ignored, and all other bus pins are driven to an idle bus state as shown in Table 4.4. If RESET and HOLD are both active at a point in time, RESET takes priority even if the 80376 was in a Hold Acknowledge state prior to RESET active.

RESET is an active HIGH, level-sensitive synchronous signal. Setup and hold times, t_{25} and t_{26}, must be met in order to assure proper operation of the 80376.

Table 4.4. Pin State (Bus Idle) during RESET

Pin Name	Signal Level during RESET
$\overline{ADS}$	1
$D_{15}-D_0$	Float
$\overline{BHE}$, $\overline{BLE}$	0
$A_{23}-A_1$	1
W/$\overline{R}$	0
D/$\overline{C}$	1
M/$\overline{IO}$	0
$\overline{LOCK}$	1
HLDA	0

4.2 Bus Transfer Mechanism

All data transfers occur as a result of one or more bus cycles. Logical data operands of byte and word lengths may be transferred without restrictions on physical address alignment. Any byte boundary may be used, although two physical bus cycles are performed as required for unaligned operand transfers.

The 80376 processor address signals are designed to simplify external system hardware. $\overline{BHE}$ and $\overline{BLE}$ provide linear selects for the two bytes of the 16-bit data bus.

Byte Enable outputs $\overline{BHE}$ and $\overline{BLE}$ are asserted when their associated data bus bytes are involved with the present bus cycle, as listed in Table 4.5.

Table 4.5. Byte Enables and Associated Data and Operand Bytes

Byte Enable	Associated Data Bus Signals
$\overline{BHE}$	$D_{15}-D_8$ (Byte 1—Most Significant)
$\overline{BLE}$	D_7-D_0 (Byte 0—Least Significant)

Each bus cycle is composed of at least two bus states. Each bus state requires one processor clock period. Additional bus states added to a single bus cycle are called wait states. See **Bus Functional Description** for additional information.

4.3 Memory and I/O Spaces

Bus cycles may access physical memory space or I/O space. Peripheral devices in the system may either be memory-mapped, or I/O-mapped, or both. As shown in Figure 4.3, physical memory addresses range from 000000H to 0FFFFFFH (16 Mbytes) and I/O addresses from 000000H to 00FFFFH (64 Kbytes). Note the I/O addresses used by the automatic I/O cycles for coprocessor communication are 8000F8H to 8000FFH, beyond the address range of programmed I/O, to allow easy generation of a coprocessor chip select signal using the A_{23} and M/$\overline{IO}$ signals.

OPERAND ALIGNMENT

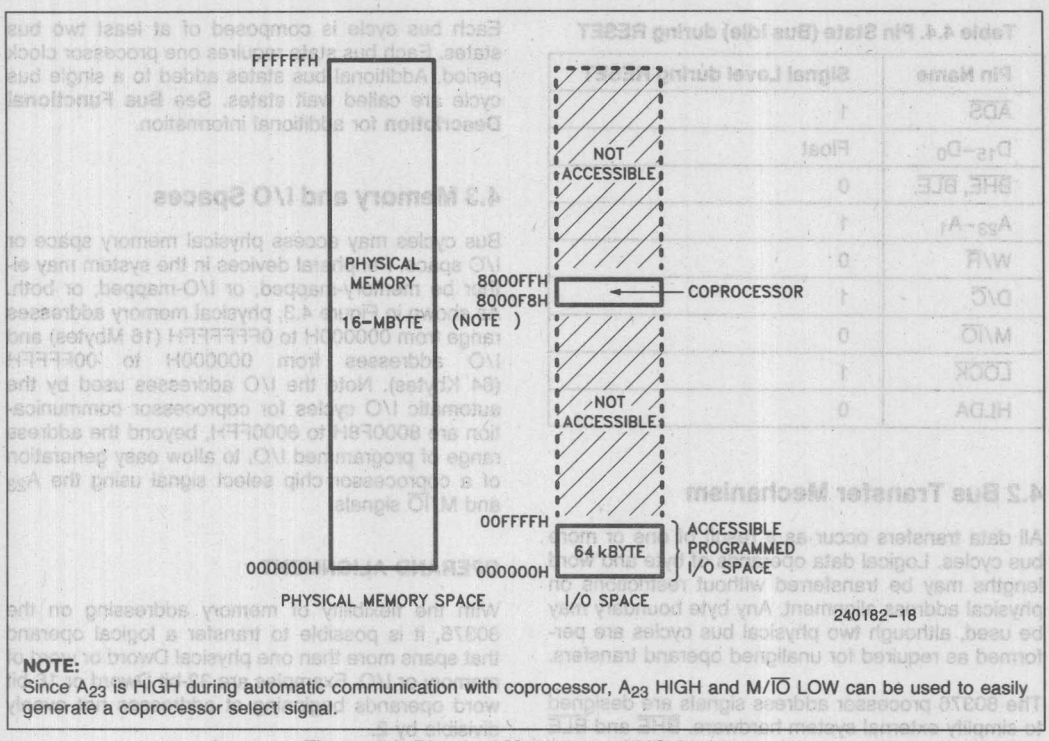
With the flexibility of memory addressing on the 80376, it is possible to transfer a logical operand that spans more than one physical Dword or word of memory or I/O. Examples are 32-bit Dword or 16-bit word operands beginning at addresses not evenly divisible by 2.

Operand alignment and size dictate when multiple bus cycles are required. Table 4.6 describes the transfer cycles generated for all combinations of logical operand lengths and alignment.

Table 4.6. Transfer Bus Cycles for Bytes, Words and Dwords

	Byte-Length of Logical Operand								
	1	2				4			
Physical Byte Address in Memory (Low-Order Bits)	xx	00	01	10	11	00	01	10	11
Transfer Cycles	b	w	lb, hb	w	hb, l,b	lw, hw	hb, lb, mw	hw, lw	mw, hb, lb

Key: b = byte transfer
w = word transfer
l = low-order portion
m = mid-order portion
x = don't care
h = high-order portion



NOTE:
Since A_{23} is HIGH during automatic communication with coprocessor, A_{23} HIGH and M/$\overline{IO}$ LOW can be used to easily generate a coprocessor select signal.

Figure 4.3. Physical Memory and I/O Spaces

4.4 Bus Functional Description

The 80376 has separate, parallel buses for data and address. The data bus is 16 bits in width, and bidirectional. The address bus provides a 24-bit value using 23 signals for the 23 upper-order address bits and 2 Byte Enable signals to directly indicate the active bytes. These buses are interpreted and controlled by several definition signals.

The definition of each bus cycle is given by three signals: M/$\overline{IO}$, W/$\overline{R}$ and D/$\overline{C}$. At the same time, a valid address is present on the byte enable signals, $\overline{BHE}$ and $\overline{BLE}$, and the other address signals A_{23}–A_1. A status signal, $\overline{ADS}$, indicates when the 80376 issues a new bus cycle definition and address.

Collectively, the address bus, data bus and all associated control signals are referred to simply as "the bus". When active, the bus performs one of the bus cycles below:

1. Read from memory space
2. Locked read from memory space
3. Write to memory space
4. Locked write to memory space
5. Read from I/O space (or coprocessor)
6. Write to I/O space (or coprocessor)
7. Interrupt acknowledge (always locked)
8. Indicate halt, or indicate shutdown

Table 4.2 shows the encoding of the bus cycle definition signals for each bus cycle. See **Bus Cycle Definition Signals** for additonal information.

When the 80376 bus is not performing one of the activities listed above, it is either Idle or in the Hold Acknowledge state, which may be detected by external circuitry. The idle state can be identified by the 80376 giving no further assertions on its address strobe output ($\overline{ADS}$) since the beginning of its most recent bus cycle, and the most recent bus cycle having been terminated. The hold acknowledge state is identified by the 80376 asserting its hold acknowledge (HLDA) output.

The shortest time unit of bus activity is a bus state. A bus state is one processor clock period (two CLK2 periods) in duration. A complete data transfer occurs during a bus cycle, composed of two or more bus states.

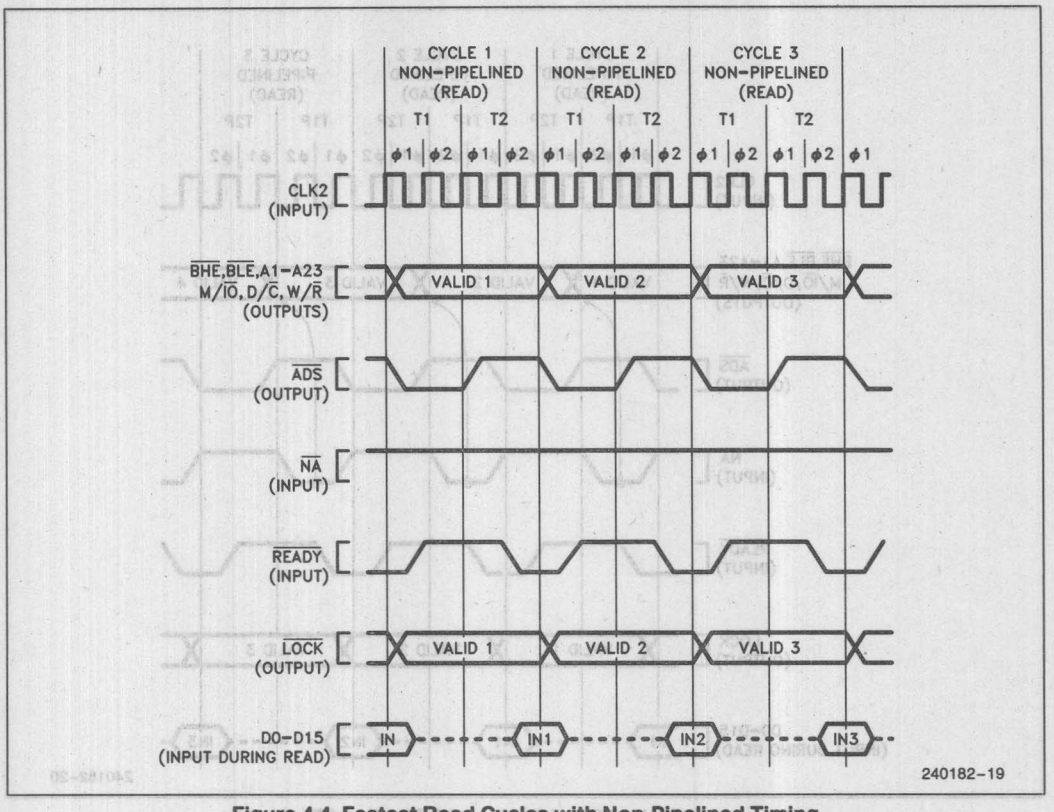


Figure 4.4. Fastest Read Cycles with Non-Pipelined Timing

The fastest 80376 bus cycle requires only two bus states. For example, three consecutive bus read cycles, each consisting of two bus states, are shown by Figure 4.4. The bus states in each cycle are named T1 and T2. Any memory or I/O address may be accessed by such a two-state bus cycle, if the external hardware is fast enough.

Every bus cycle continues until it is acknowledged by the external system hardware, using the 80376 $\overline{\text{READY}}$ input. Acknowledging the bus cycle at the end of the first T2 results in the shortest bus cycle, requiring only T1 and T2. If $\overline{\text{READY}}$ is not immediately asserted however, T2 states are repeated indefinitely until the $\overline{\text{READY}}$ input is sampled active.

The pipelining option provides a choice of bus cycle timings. Pipelined or non-pipelined cycles are selectable on a cycle-by-cycle basis with the Next Address ($\overline{\text{NA}}$) input.

When pipelining is selected the address ($\overline{\text{BHE}}$, $\overline{\text{BLE}}$ and A_{23}–A_1) and definition (W/$\overline{\text{R}}$, D/$\overline{\text{C}}$, M/$\overline{\text{IO}}$ and $\overline{\text{LOCK}}$) of the next cycle are available before the end of the current cycle. To signal their availability, the 80376 address status output ($\overline{\text{ADS}}$) is asserted. Figure 4.5 illustrates the fastest read cycles with pipelined timing.

Note from Figure 4.5 the fastest bus cycles using pipelining require only two bus states, named **T1P** and **T2P**. Therefore pipelined cycles allow the same data bandwidth as non-pipelined cycles, but address-to-data access time is increased by one T-state time compared to that of a non-pipelined cycle.

9

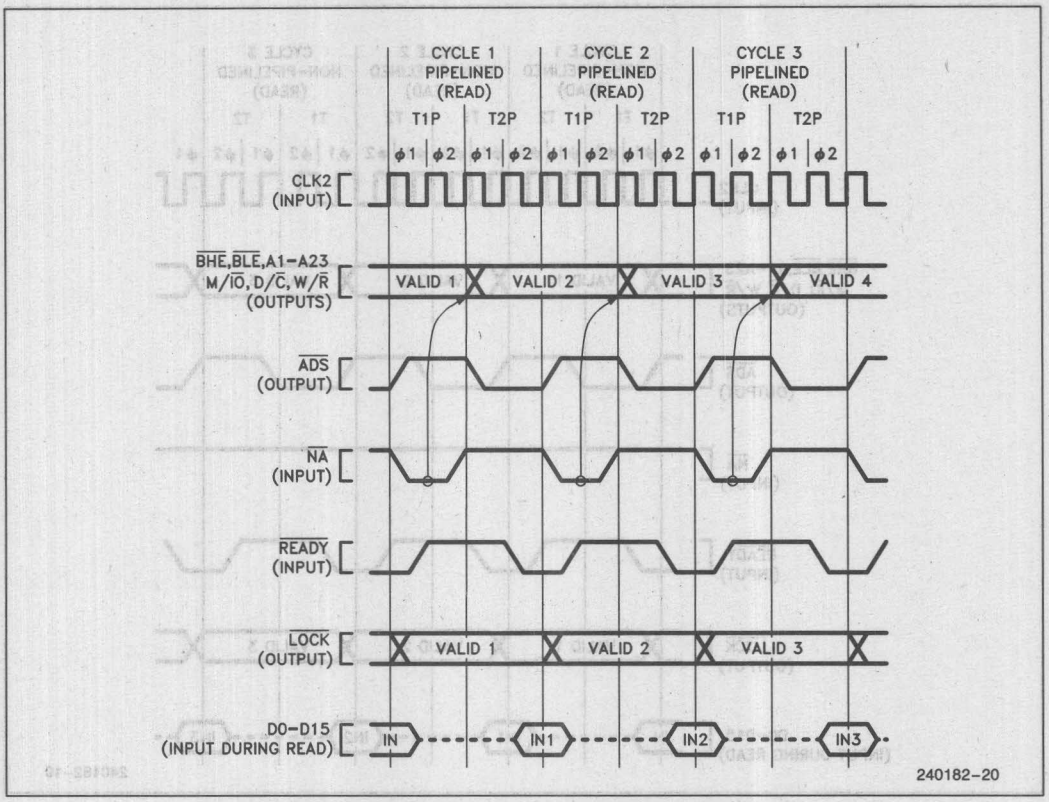


Figure 4.5. Fastest Read Cycles with Pipelined Timing

READ AND WRITE CYCLES

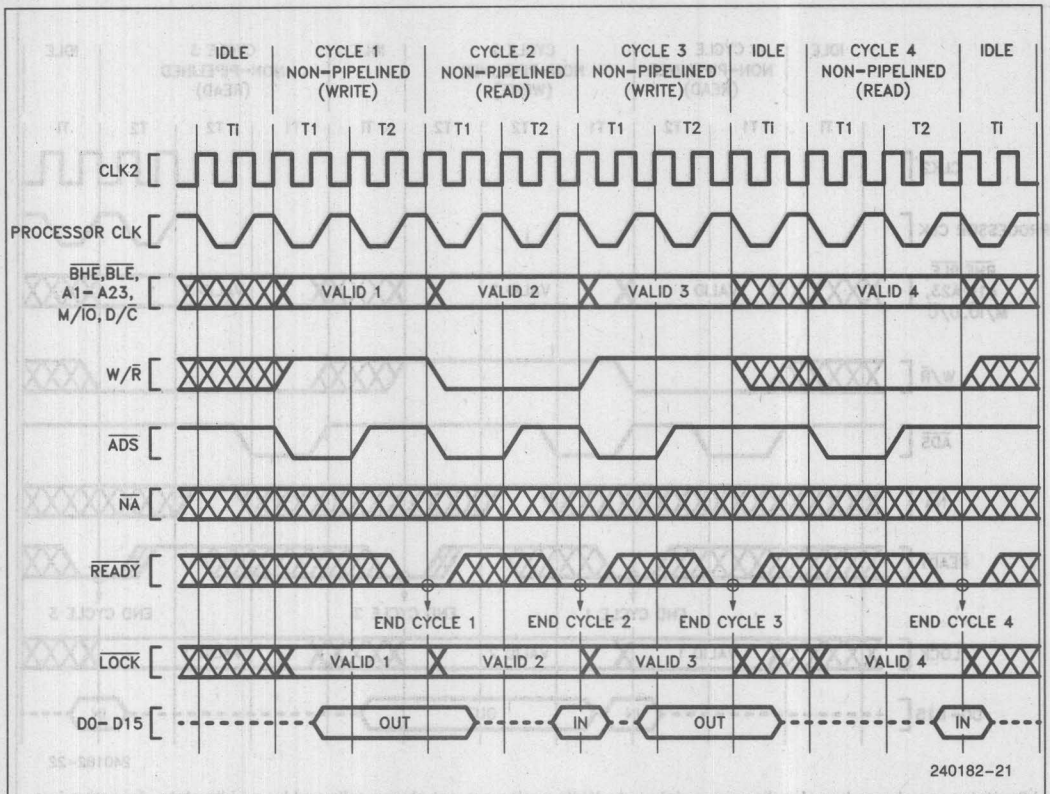
Data transfers occur as a result of bus cycles, classified as read or write cycles. During read cycles, data is transferred from an external device to the processor. During write cycles, data is transferred from the processor to an external device.

Two choices of bus cycle timing are dynamically selectable: non-pipelined or pipelined. After an idle bus state, the processor always uses non-pipelined timing. However the NA (Next Address) input may be asserted to select pipelined timing for the next bus cycle. When pipelining is selected and the 80376 has a bus request pending internally, the address and definition of the next cycle is made available even before the current bus cycle is acknowledged by READY.

Terminating a read or write cycle, like any bus cycle, requires acknowledging the cycle by asserting the READY input. Until acknowledged, the processor inserts wait states into the bus cycle, to allow adjustment for the speed of any external device. External hardware, which has decoded the address and bus cycle type, asserts the READY input at the appropriate time.

At the end of the second bus state within the bus cycle, READY is sampled. At that time, if external hardware acknowledges the bus cycle by asserting READY, the bus cycle terminates as shown in Figure 4.6. If READY is negated as in Figure 4.7, the 80376 executes another bus state (a wait state) and READY is sampled again at the end of that state. This continues indefinitely until the cycle is acknowledged by READY asserted.

When the current cycle is acknowledged, the 80376 terminates it. When a read cycle is acknowledged, the 80376 latches the information present at its data pins. When a write cycle is acknowledged, the write data of the 80376 remains valid throughout phase one of the next bus state, to provide write data hold time.



Idle states are shown here for diagram variety only. Write cycles are not always followed by an idle state. An active bus cycle can immediately follow the write cycle.

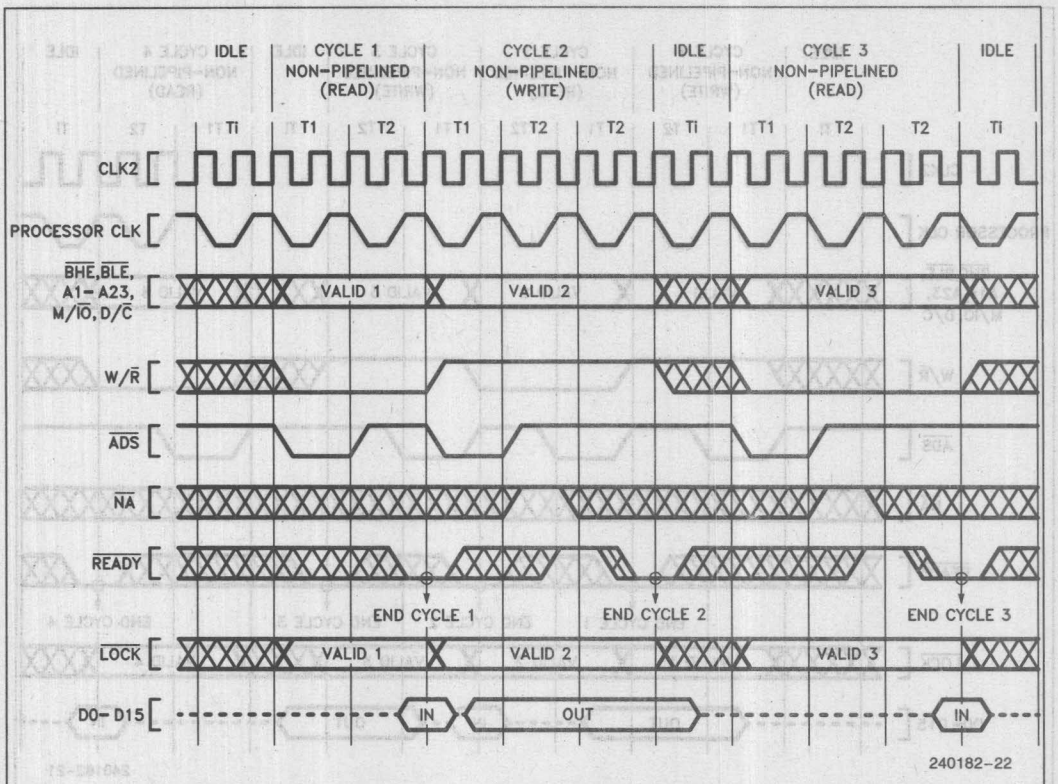
Figure 4.6. Various Non-Pipelined Bus Cycles (Zero Wait States)

Non-Pipelined Bus Cycles

Any bus cycle may be performed with non-pipelined timing. For example, Figure 4.6 shows a mixture of non-pipelined read and write cycles. Figure 4.6 shows that the fastest possible non-pipelined cycles have two bus states per bus cycle. The states are named T1 and T2. In phase one of T1, the address signals and bus cycle definition signals are driven valid and, to signal their availability, address strobe ($\overline{ADS}$) is simultaneously asserted.

During read or write cycles, the data bus behaves as follows. If the cycle is a read, the 80376 floats its data signals to allow driving by the external device being addressed. **The 80376 requires that all data bus pins be at a valid logic state (HIGH or LOW) at the end of each read cycle, when $\overline{READY}$ is asserted. The system MUST be designed to meet this requirement.** If the cycle is a write, data signals are driven by the 80376 beginning in phase two of T1 until phase one of the bus state following cycle acknowledgement.

9



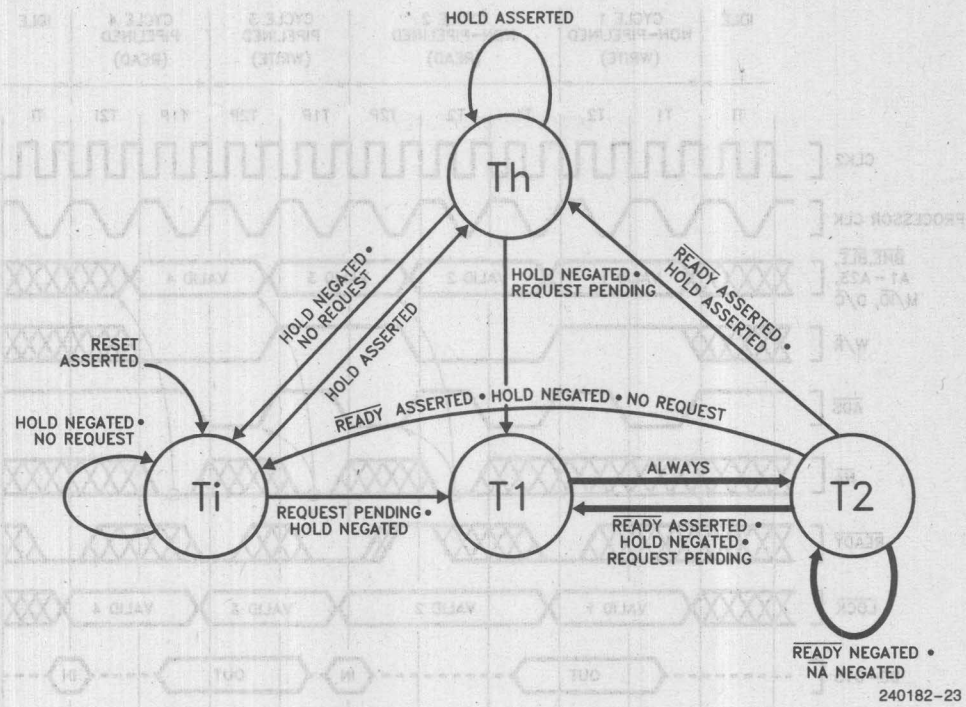
Idle states are shown here for diagram variety only. Write cycles are not always followed by an idle state. An active bus cycle can immediately follow the write cycle.

Figure 4.7. Various Non-Pipelined Bus Cycles (Various Number of Wait States)

Figure 4.7 illustrates non-pipelined bus cycles with one wait state added to Cycles 2 and 3. $\overline{\text{READY}}$ is sampled inactive at the end of the first T2 in Cycles 2 and 3. Therefore Cycles 2 and 3 have T2 repeated again. At the end of the second T2, $\overline{\text{READY}}$ is sampled active.

When address pipelining is not used, the address and bus cycle definition remain valid during all wait states. When wait states are added and it is desirable to maintain non-pipelined timing, it is necessary to negate $\overline{\text{NA}}$ during each T2 state except the last one, as shown in Figure 4.7, Cycles 2 and 3. If $\overline{\text{NA}}$ is sampled active during a T2 other than the last one, the next state would be T2I or T2P instead of another T2.

When address pipelining is not used, the bus states and transitions are completely illustrated by Figure 4.8. The bus transitions between four possible states, T1, T2, T_i, and T_h. Bus cycles consist of T1 and T2, with T2 being repeated for wait states. Otherwise the bus may be idle, T_i, or in the hold acknowledge state T_h.



Bus States:
T1—first clock of a non-pipelined bus cycle (80376 drives new address and asserts $\overline{ADS}$).
T2—subsequent clocks of a bus cycle when $\overline{NA}$ has not been sampled asserted in the current bus cycle.
Ti—idle state.
Th—hold acknowledge state (80376 asserts HLDA).
The fastest bus cycle consists of two states: T1 and T2.
Four basic bus states describe bus operation when not using pipelined address.

Figure 4.8. 80376 Bus States (Not Using Pipelined Address)

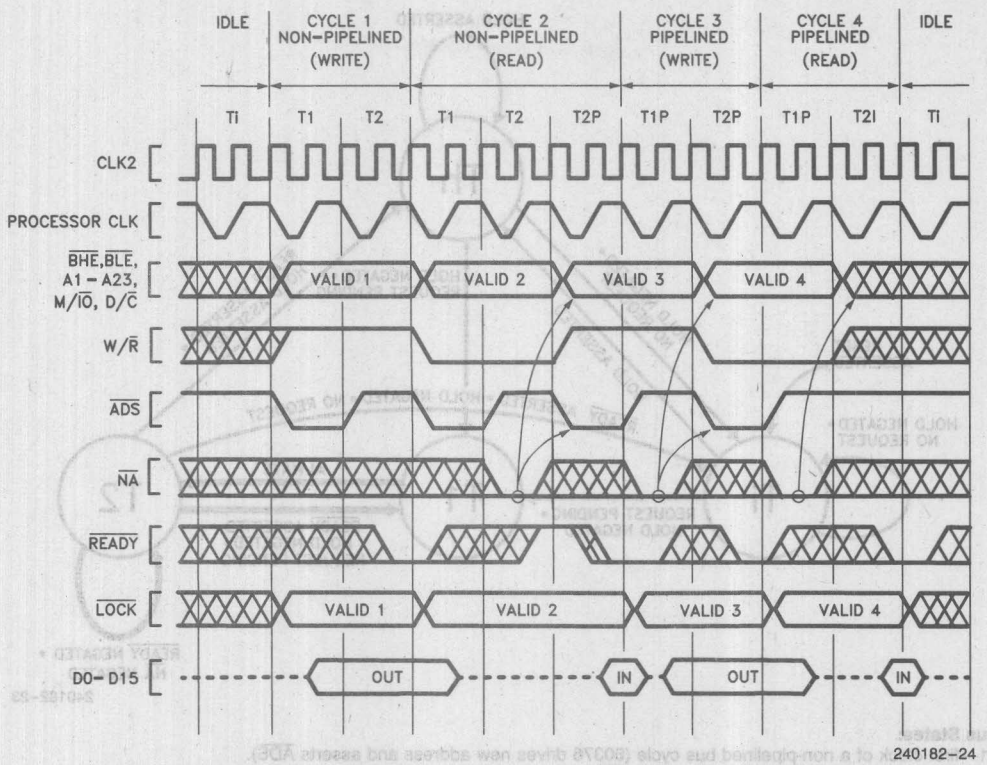
Bus cycles always begin with T1. T1 always leads to T2. If a bus cycle is not acknowledged during T2 and $\overline{NA}$ is inactive, T2 is repeated. When a cycle is acknowledged during T2, the following state will be T1 of the next bus cycle if a bus request is pending internally, or T_i if there is no bus request pending, or T_h if the HOLD input is being asserted.

Use of pipelining allows the 80376 to enter three additional bus states not shown in Figure 4.8. Figure 4.12 is the complete bus state diagram, including pipelined cycles.

Pipelined Bus Cycles

Pipelining is the option of requesting the address and the bus cycle definition of the next internally pending bus cycle before the current bus cycle is acknowledged with $\overline{READY}$ asserted. $\overline{ADS}$ is asserted by the 80376 when the next address is issued. The pipelining option is controlled on a cycle-by-cycle basis with the $\overline{NA}$ input signal.

Once a bus cycle is in progress and the current address has been valid for at least one entire bus state, the $\overline{NA}$ input is sampled at the end of every phase one until the bus cycle is acknowledged. During non-pipelined bus cycles $\overline{NA}$ is sampled at the end of phase one in every T2. An example is Cycle 2 in Figure 4.9, during which $\overline{NA}$ is sampled at the end of phase one of every T2 (it was asserted once during the first T2 and has no further effect during that bus cycle).



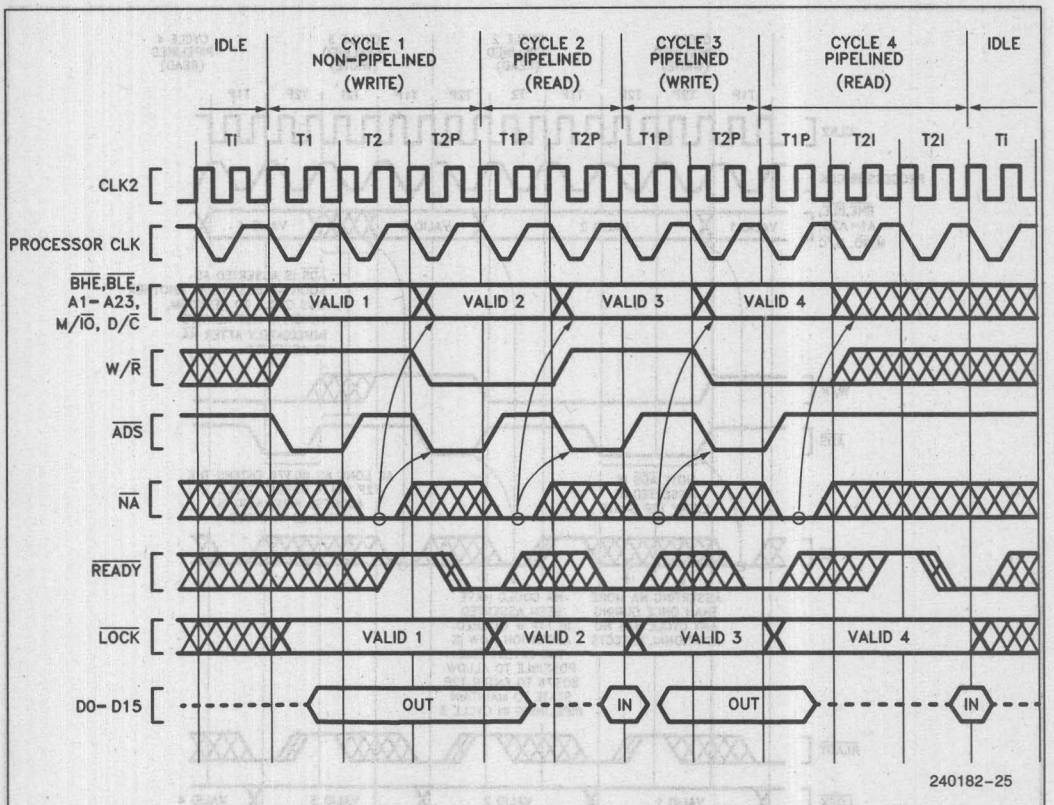
Following any idle bus state (Ti), bus cycles are non-pipelined. Within non-pipelined bus cycles, NA is only sampled during wait states. Therefore, to begin pipelining during a group of non-pipelined bus cycles requires a non-pipelined cycle with at least one wait state (Cylcle 2 above).

Figure 4.9. Transitioning to Pipelining during Burst of Bus Cycles

If NA is sampled active, the 80376 is free to drive the address and bus cycle definition of the next bus cycle, and assert ADS, as soon as it has a bus request internally pending. It may drive the next address as early as the next bus state, whether the current bus cycle is acknowledged at that time or not.

Regarding the details of pipelining, the 80376 has the following characteristics:

1. The next address and status may appear as early as the bus state after NA was sampled active (see Figures 4.9 or 4.10). In that case, state T2P is entered immediately. However, when there is not an internal bus request already pending, the next address and status will not be available immediately after NA is asserted and T2I is entered instead of T2P (see Figure 4.11 Cycle 3). Provided *the current bus cycle isn't yet acknowledged* by READY asserted, T2P will be entered as soon as the 80376 does drive the next address and status. External hardware should therefore observe the ADS output as confirmation the next address and status are actually being driven on the bus.
2. Any address and status which are validated by a pulse on the 80376 ADS output will remain stable on the address pins for at least two processor clock periods. The 80376 cannot produce a new address and status more frequently than every two processor clock periods (see Figures 4.9, 4.10 and 4.11).
3. Only the address and bus cycle definition of the very next bus cycle is available. The pipelining capability cannot look further than one bus cycle ahead (see Figure 4.11, Cycle 1).



Following any idle bus state (Ti) the bus cycle is always non-pipelined and $\overline{NA}$ is only sampled during wait states. To start, address pipelining after an idle state requires a non-pipelined cycle with at least one wait state (cycle 1 above). The pipelined cycles (2, 3, 4 above) are shown with various numbers of wait states.

Figure 4.10. Fastest Transition to Pipelined Bus Cycle Following Idle Bus State

The complete bus state transition diagram, including pipelining is given by Figure 4.12. Note it is a superset of the diagram for non-pipelined only, and the three additional bus states for pipelining are drawn in bold.

The fastest bus cycle with pipelining consists of just two bus states, T1P and T2P (recall for non-pipelined it is T1 and T2). T1P is the first bus state of a pipelined cycle.

Initiating and Maintaining Pipelined Bus Cycles

Using the state diagram Figure 4.12, observe the transitions from an idle state, T_i, to the beginning of a pipelined bus cycle T1P. From an idle state, T_i, the first bus cycle must begin with T1, and is therefore a non-pipelined bus cycle. The next bus cycle will be pipelined, however, provided $\overline{NA}$ is asserted and the first bus cycle ends in a T2P state (the address and status for the next bus cycle is driven during T2P). The fastest path from an idle state to a pipelined bus cycle is shown in bold below:

T_i, T_i,	**T1-T2-T2P,**	**T1P-T2P,**
idle states	non-pipelined cycle	pipelined cycle

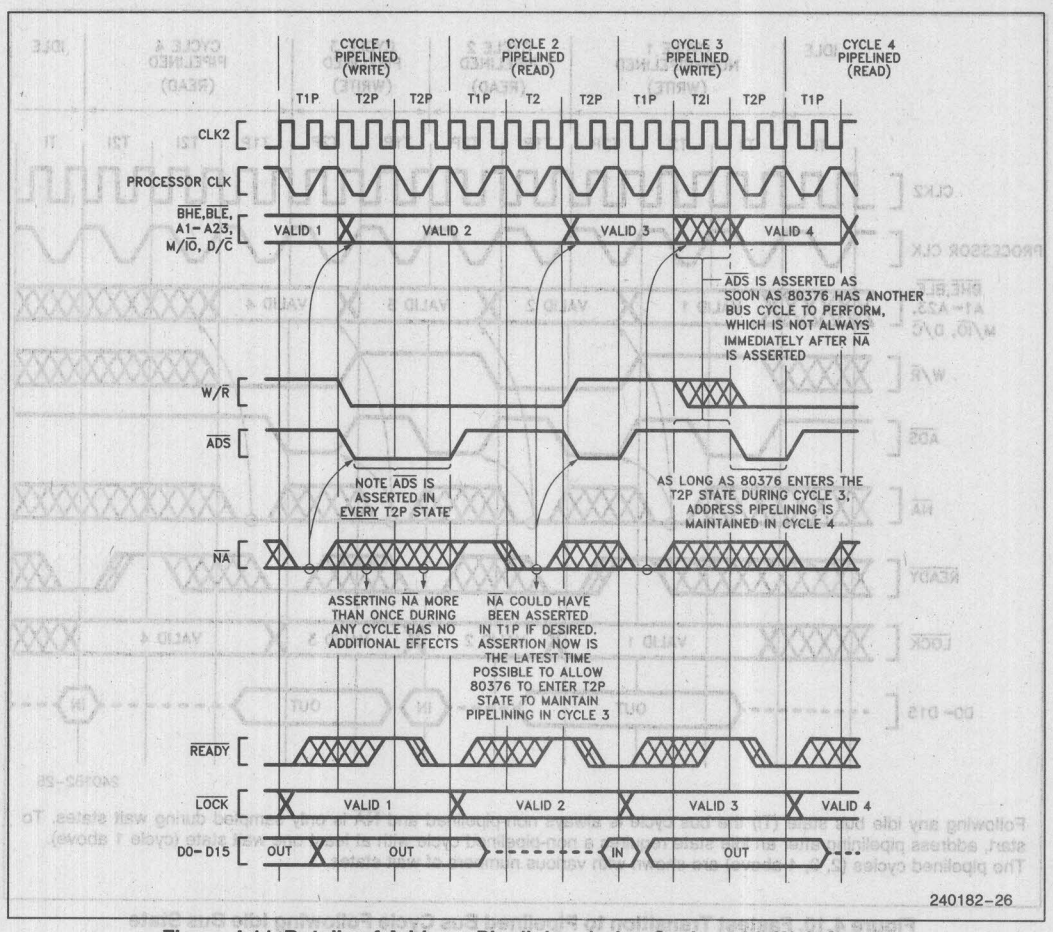


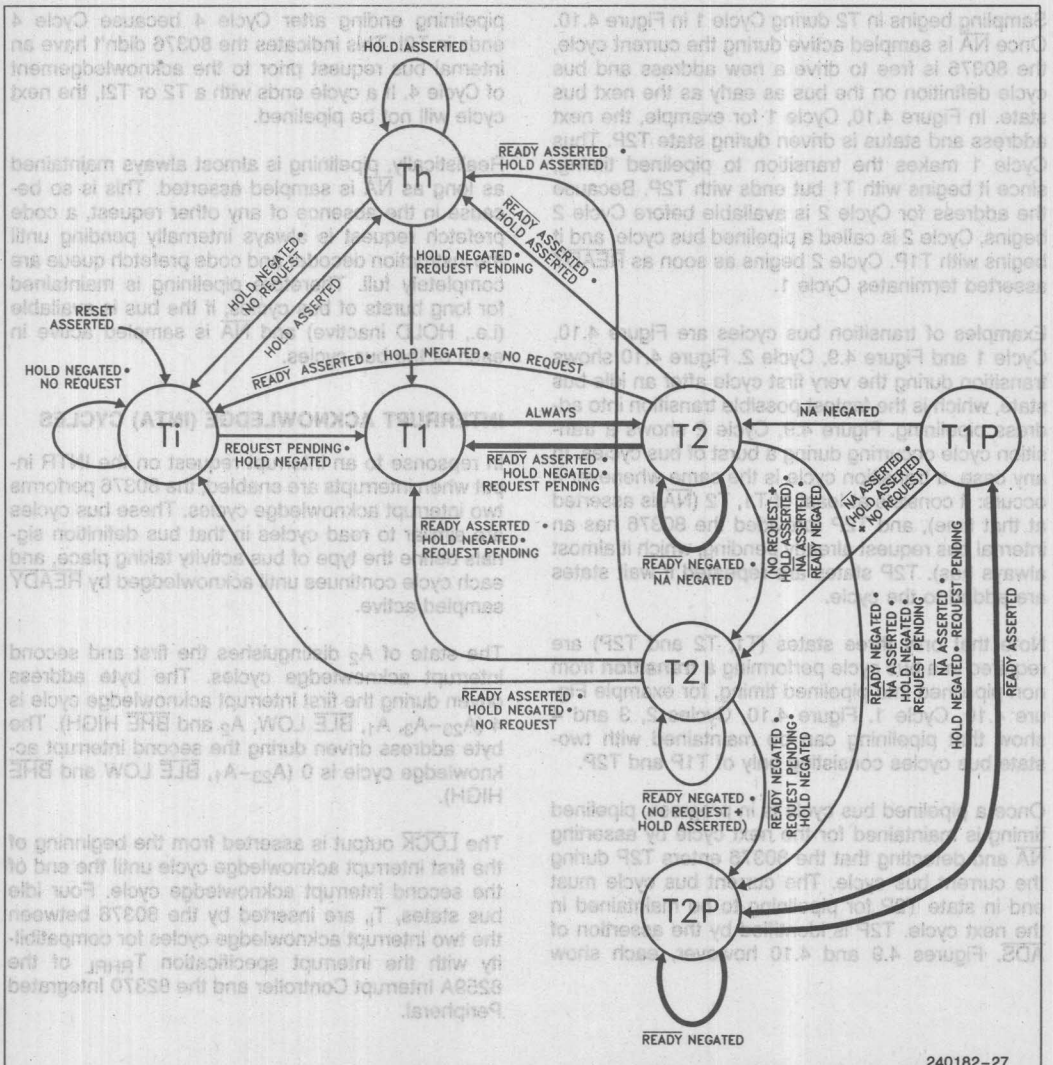
Figure 4.11. Details of Address Pipelining during Cycles with Wait States

T1–T2–T2P are the states of the bus cycle that establishes address pipelining for the next bus cycle, which begins with T1P. The same is true after a bus hold state, shown below:

T_h, T_h, T_h,	T1–T2–T2P,	T1P–T2P,
hold states	aknowledge non-pipelined cycle	pipelined cycle

The transition to pipelined address is shown functionally by Figure 4.10, Cycle 1. Note that Cycle 1 is used to transition into pipelined address timing for the subsequent Cycles 2, 3 and 4, which are pipelined. The $\overline{NA}$ input is asserted at the appropriate time to select address pipelining for Cycles 2, 3 and 4.

Once a bus cycle is in progress and the current address and status has been valid for one entire bus state, the $\overline{NA}$ input is sampled at the end of every phase one until the bus cycle is acknowledged.



Bus States:
T1—first clock of a non-pipelined bus cycle (80376 drives new address, status and asserts $\overline{ADS}$).
T2—subsequent clocks of a bus cycle when $\overline{NA}$ has not been sampled asserted in the current bus cycle.
T2I—subsequent clocks of a bus cycle when $\overline{NA}$ has been sampled asserted in the current bus cycle but there is not yet an internal bus request pending (80376 will not drive new address, status or assert $\overline{ADS}$).
T2P—subsequent clocks of a bus cycle when $\overline{NA}$ has been sampled asserted in the current bus cycle and there is an internal bus request pending (80376 drives new address, status and asserts $\overline{ADS}$).
T1P—first clock of a pipelined bus cycle.
Ti—idle state.
Th—hold acknowledge state (80376 asserts HLDA).
Asserting $\overline{NA}$ for pipelined bus cycles gives access to three more bus states: T2I, T2P and T1P.
Using pipelining the fastest bus cycle consists of T1P and T2P.

Figure 4.12. 80376 Processor Complete Bus States (Including Pipelining)

Sampling begins in T2 during Cycle 1 in Figure 4.10. Once $\overline{NA}$ is sampled active during the current cycle, the 80376 is free to drive a new address and bus cycle definition on the bus as early as the next bus state. In Figure 4.10, Cycle 1 for example, the next address and status is driven during state T2P. Thus Cycle 1 makes the transition to pipelined timing, since it begins with T1 but ends with T2P. Because the address for Cycle 2 is available before Cycle 2 begins, Cycle 2 is called a pipelined bus cycle, and it begins with T1P. Cycle 2 begins as soon as $\overline{READY}$ asserted terminates Cycle 1.

Examples of transition bus cycles are Figure 4.10, Cycle 1 and Figure 4.9, Cycle 2. Figure 4.10 shows transition during the very first cycle after an idle bus state, which is the fastest possible transition into address pipelining. Figure 4.9, Cycle 2 shows a transition cycle occurring during a burst of bus cycles. In any case, a transition cycle is the same whenever it occurs: it consists at least of T1, T2 ($\overline{NA}$ is asserted at that time), and T2P (provided the 80376 has an internal bus request already pending, which it almost always has). T2P states are repeated if wait states are added to the cycle.

Note that only three states (T1, T2 and T2P) are required in a bus cycle performing a **transition** from non-pipelined into pipelined timing, for example Figure 4.10, Cycle 1. Figure 4.10, Cycles 2, 3 and 4 show that pipelining can be maintained with two-state bus cycles consisting only of T1P and T2P.

Once a pipelined bus cycle is in progress, pipelined timing is maintained for the next cycle by asserting $\overline{NA}$ and detecting that the 80376 enters T2P during the current bus cycle. The current bus cycle must end in state T2P for pipelining to be maintained in the next cycle. T2P is identified by the assertion of $\overline{ADS}$. Figures 4.9 and 4.10 however, each show pipelining ending after Cycle 4 because Cycle 4 ends in T2I. This indicates the 80376 didn't have an internal bus request prior to the acknowledgement of Cycle 4. If a cycle ends with a T2 or T2I, the next cycle will not be pipelined.

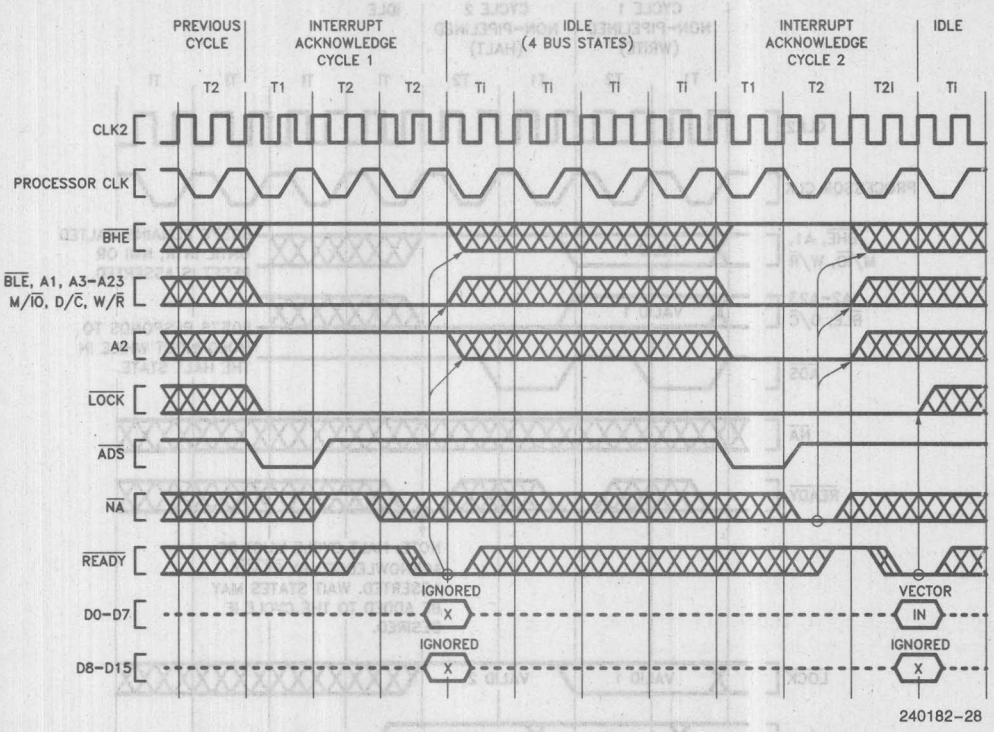
Realistically, pipelining is almost always maintained as long as $\overline{NA}$ is sampled asserted. This is so because in the absence of any other request, a code prefetch request is always internally pending until the instruction decoder and code prefetch queue are completely full. Therefore pipelining is maintained for long bursts of bus cycles, if the bus is available (i.e., HOLD inactive) and $\overline{NA}$ is sampled active in each of the bus cycles.

INTERRUPT ACKNOWLEDGE (INTA) CYCLES

In repsonse to an interrupt request on the INTR input when interrupts are enabled, the 80376 performs two interrupt acknowledge cycles. These bus cycles are similar to read cycles in that bus definition signals define the type of bus activity taking place, and each cycle continues until acknowledged by $\overline{READY}$ sampled active.

The state of A_2 distinguishes the first and second interrupt acknowledge cycles. The byte address driven during the first interrupt acknowledge cycle is 4 (A_{23}–A_3, A_1, $\overline{BLE}$ LOW, A_2 and $\overline{BHE}$ HIGH). The byte address driven during the second interrupt acknowledge cycle is 0 (A_{23}–A_1, $\overline{BLE}$ LOW and $\overline{BHE}$ HIGH).

The $\overline{LOCK}$ output is asserted from the beginning of the first interrupt acknowledge cycle until the end of the second interrupt acknowledge cycle. Four idle bus states, T_i, are inserted by the 80376 between the two interrupt acknowledge cycles for compatibility with the interrupt specification T_{RHRL} of the 8259A Interrupt Controller and the 82370 Integrated Peripheral.



Interrupt Vector (0–255) is read on D0–D7 at end of second Interrupt Acknowledge bus cycle.
Because each Interrupt Acknowledge bus cycle is followed by idle bus states, asserting NA has no practical effect. Choose the approach which is simplest for your system hardware design.

Figure 4.13. Interrupt Acknowledge Cycles

During both interrupt acknowledge cycles, D_{15}–D_0 float. No data is read at the end of the first interrupt acknowledge cycle. At the end of the second interrupt acknowledge cycle, the 80376 will read an external interrupt vector from D_7–D_0 of the data bus. The vector indicates the specific interrupt number (from 0–255) requiring service.

HALT INDICATION CYCLE

The 80376 execution unit halts as a result of executing a HLT instruction. Signaling its entrance into the halt state, a halt indication cycle is performed. The halt indication cycle is identified by the state of the bus definition signals and a byte address of 2. See the **Bus Cycle Definition Signals** section. The halt indication cycle must be acknowledged by READY asserted. A halted 80376 resumes execution when INTR (if interrupts are enabled), NMI or RESET is asserted.

9

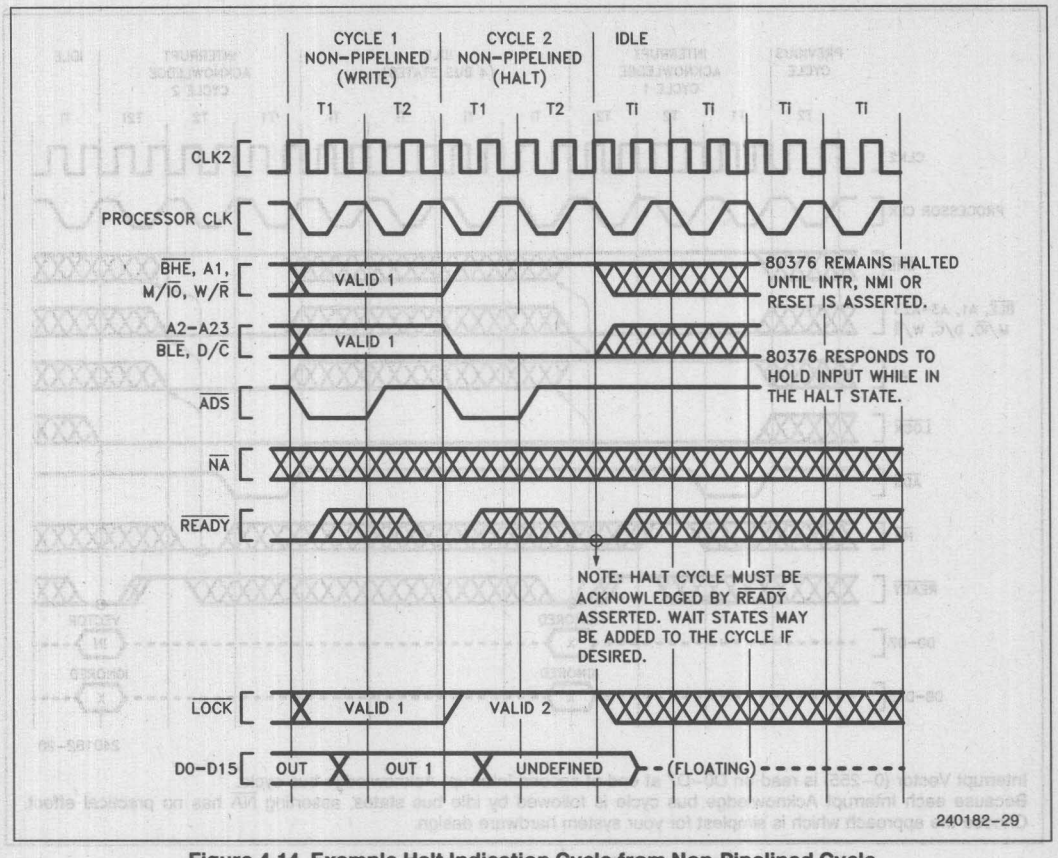


Figure 4.14. Example Halt Indication Cycle from Non-Pipelined Cycle

SHUTDOWN INDICATION CYCLE

The 80376 shuts down as a result of a protection fault while attempting to process a double fault. Signaling its entrance into the shutdown state, a shutdown indication cycle is performed. The shutdown indication cycle is identified by the state of the bus definition signals shown in **Bus Cycle Definition Signals** and a byte address of 0. The shutdown indication cycle must be acknowledged by $\overline{\text{READY}}$ asserted. A shutdown 80376 resumes execution when NMI or RESET is asserted.

ENTERING AND EXITING HOLD ACKNOWLEDGE

The bus hold acknowledge state, T_h, is entered in response to the HOLD input being asserted. In the bus hold acknowledge state, the 80376 floats all outputs or bidirectional signals, except for HLDA. HLDA is asserted as long as the 80376 remains in the bus hold acknowledge state. In the bus hold acknowledge state, all inputs except HOLD and RESET are ignored.

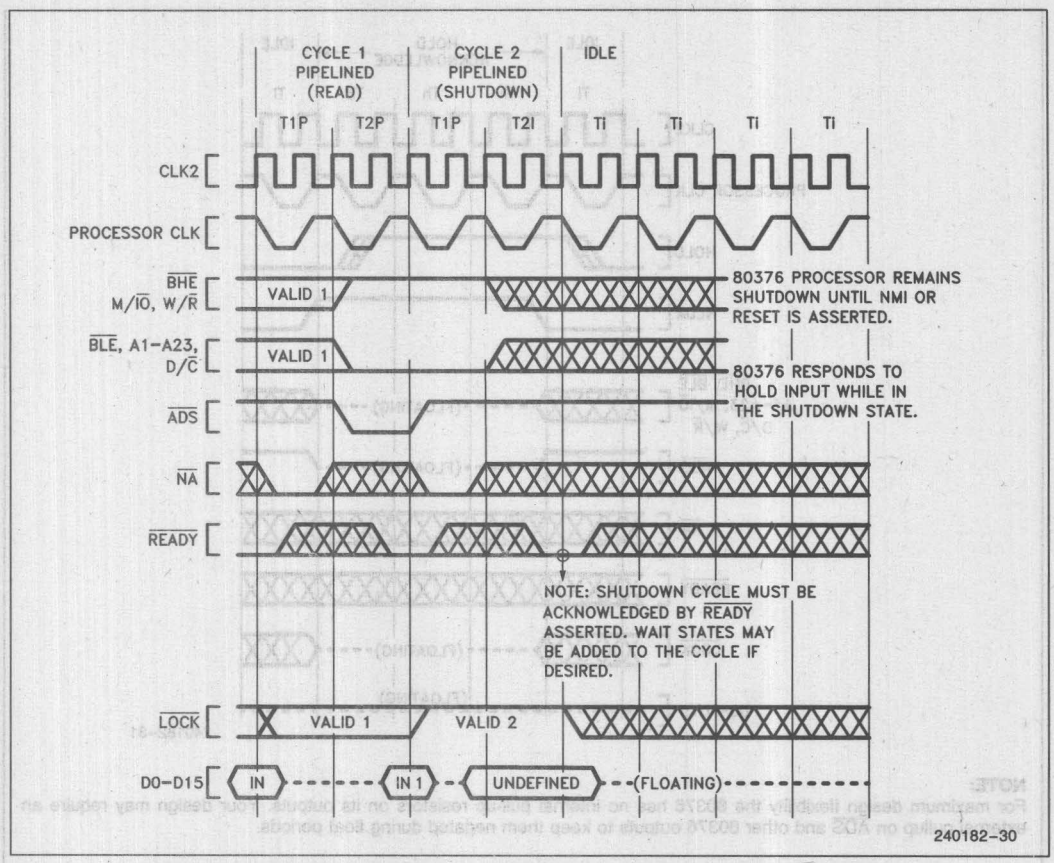


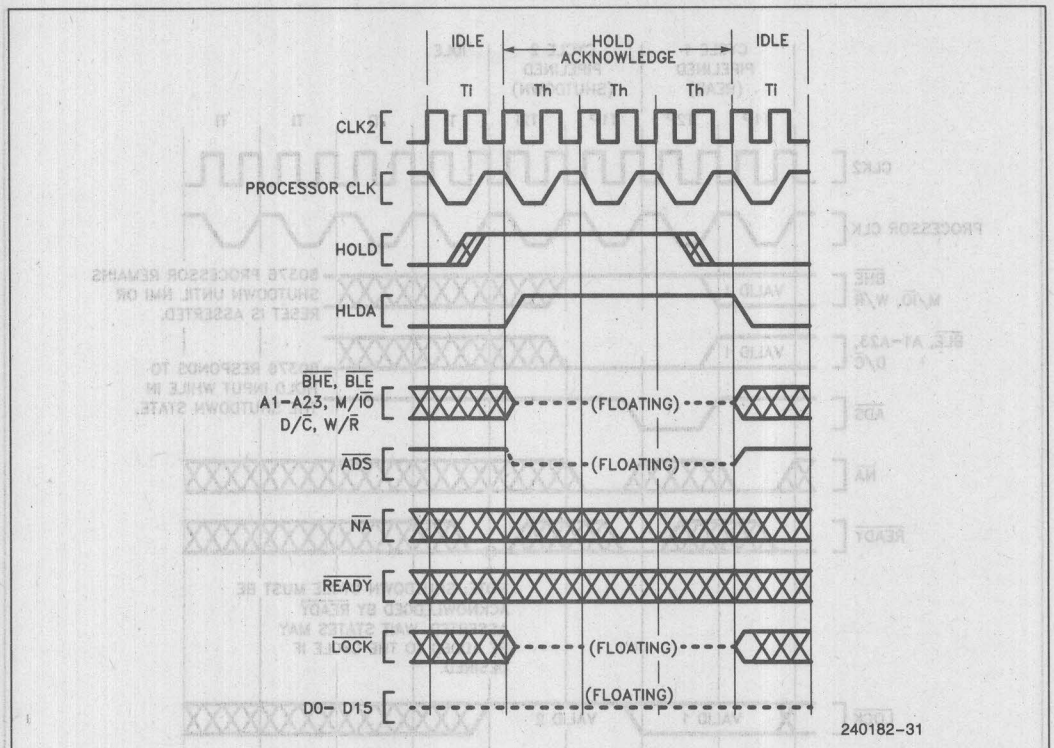
Figure 4.15. Example Shutdown Indication Cycle from Non-Pipelined Cycle

T_h may be entered from a bus idle state as in Figure 4.16 or after the acknowledgement of the current physical bus cycle if the LOCK signal is not asserted, as in Figures 4.17 and 4.18.

T_h is exited in response to the HOLD input being negated. The following state will be T_i as in Figure 4.16 if no bus request is pending. The following bus state will be T1 if a bus request is internally pending, as in Figures 4.17 and 4.18. T_h is exited in response to RESET being asserted.

If a rising edge occurs on the edge-triggered NMI input while in T_h, the event is remembered as a non-maskable interrupt 2 and is serviced when T_h is exited unless the 80376 is reset before T_h is exited.

9



NOTE:
For maximum design flexibility the 80376 has no internal pull-up resistors on its outputs. Your design may require an external pullup on $\overline{ADS}$ and other 80376 outputs to keep them negated during float periods.

Figure 4.16. Requesting Hold from Idle Bus

RESET DURING HOLD ACKNOWLEDGE

RESET being asserted takes priority over HOLD being asserted. If RESET is asserted while HOLD remains asserted, the 80376 drives its pins to defined states during reset, as in **Table 4.5, Pin State During Reset,** and performs internal reset activity as usual.

If HOLD remains asserted when RESET is inactive, the 80376 enters the hold acknowledge state before performing its first bus cycle, provided HOLD is still asserted when the 80376 processor would otherwise perform its first bus cycle. If HOLD remains asserted when RESET is inactive, the $\overline{BUSY}$ input is still sampled as usual to determine whether a self test is being requested.

FLOAT

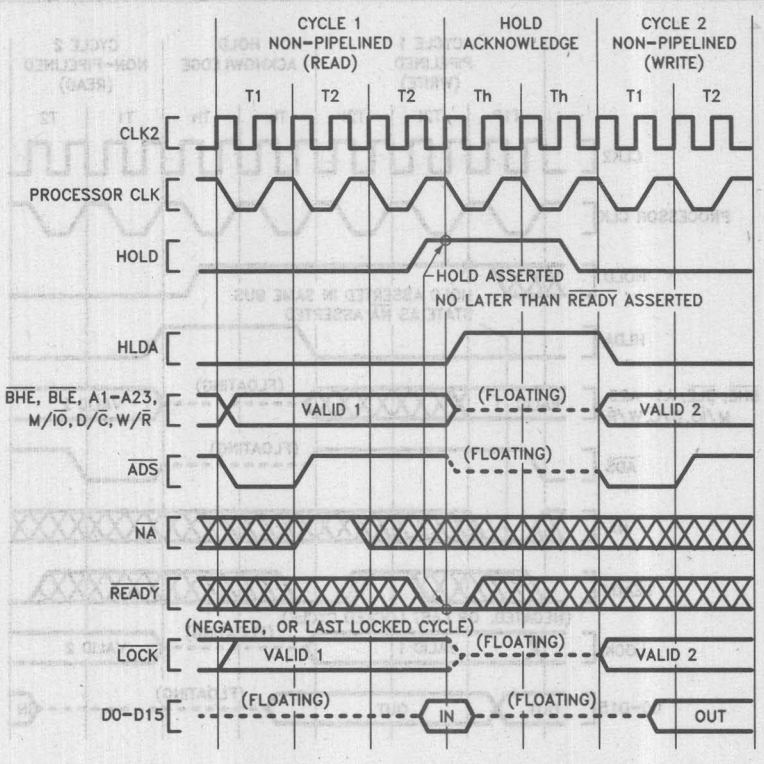
Activating the $\overline{FLT}$ input floats all 80376 bidirectional and output signals, including HLDA. Asserting $\overline{FLT}$ isolates the 80376 from the surrounding circuitry.

When an 80376 in a PQFP surface-mount package is used without a socket, it cannot be removed from the printed circuit board. The $\overline{FLT}$ input allows the 80376 to be electrically isolated to allow testing of external circuitry. This technique is known as ON-CE™ for "ON-Circuit Emulation".

ENTERING AND EXITING FLOAT

$\overline{FLT}$ is an asynchronous, active-low input. It is recognized on the rising edge of CLK2. When recognized, it aborts the current bus cycle and floats the outputs of the 80376 (Figure 4.20). $\overline{FLT}$ must be held low for a minimum of 16 CLK2 cycles. Reset should be asserted and held asserted until after $\overline{FLT}$ is deasserted. This will ensure that the 80376 will exit float in a valid state.

Asserting the $\overline{FLT}$ input unconditionally aborts the current bus cycle and forces the 80376 into the FLOAT mode. Since activating $\overline{FLT}$ unconditionally forces the 80376 into FLOAT mode, the 80376 is not



NOTE:
HOLD is a synchronous input and can be asserted at any CLK2 edge, provided setup and hold (t_{23} and t_{24}) requirements are met. This waveform is useful for determining Hold Acknowledge latency.

Figure 4.17. Requesting Hold from Active Bus ($\overline{NA}$ Inactive)

guaranteed to enter FLOAT in a valid state. After deactivating $\overline{FLT}$, the 80376 is not guaranteed to exit FLOAT mode in a valid state. This is not a problem as the $\overline{FLT}$ pin is meant to be used only during ONCE. After exiting FLOAT, the 80376 must be reset to return it to a valid state. Reset should be asserted before $\overline{FLT}$ is deasserted. This will ensure that the 80376 will exit float in a valid state.

$\overline{FLT}$ has an internal pull-up resistor, and if it is not used it should be unconnected.

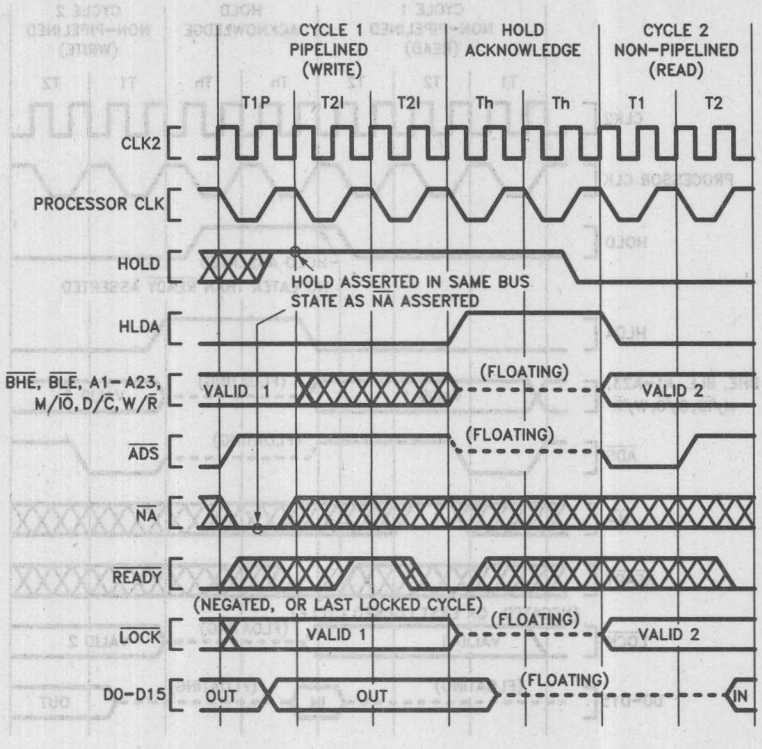
BUS ACTIVITY DURING AND FOLLOWING RESET

RESET is the highest priority input signal, capable of interrupting any processor activity when it is asserted. A bus cycle in progress can be aborted at any stage, or idle states or bus hold acknowledge states discontinued so that the reset state is established.

RESET should remain asserted for at least 15 CLK2 periods to ensure it is recognized throughout the 80376, and at least 80 CLK2 periods if a 80376 self-test is going to be requested at the falling edge. RESET asserted pulses less than 15 CLK2 periods may not be recognized. RESET pulses less than 80 CLK2 periods followed by a self-test may cause the self-test to report a failure when no true failure exists.

Provided the RESET falling edge meets setup and hold times t_{25} and t_{26}, the internal processor clock phase is defined at that time as illustrated by Figure 4.19 and Figure 6.7.

9

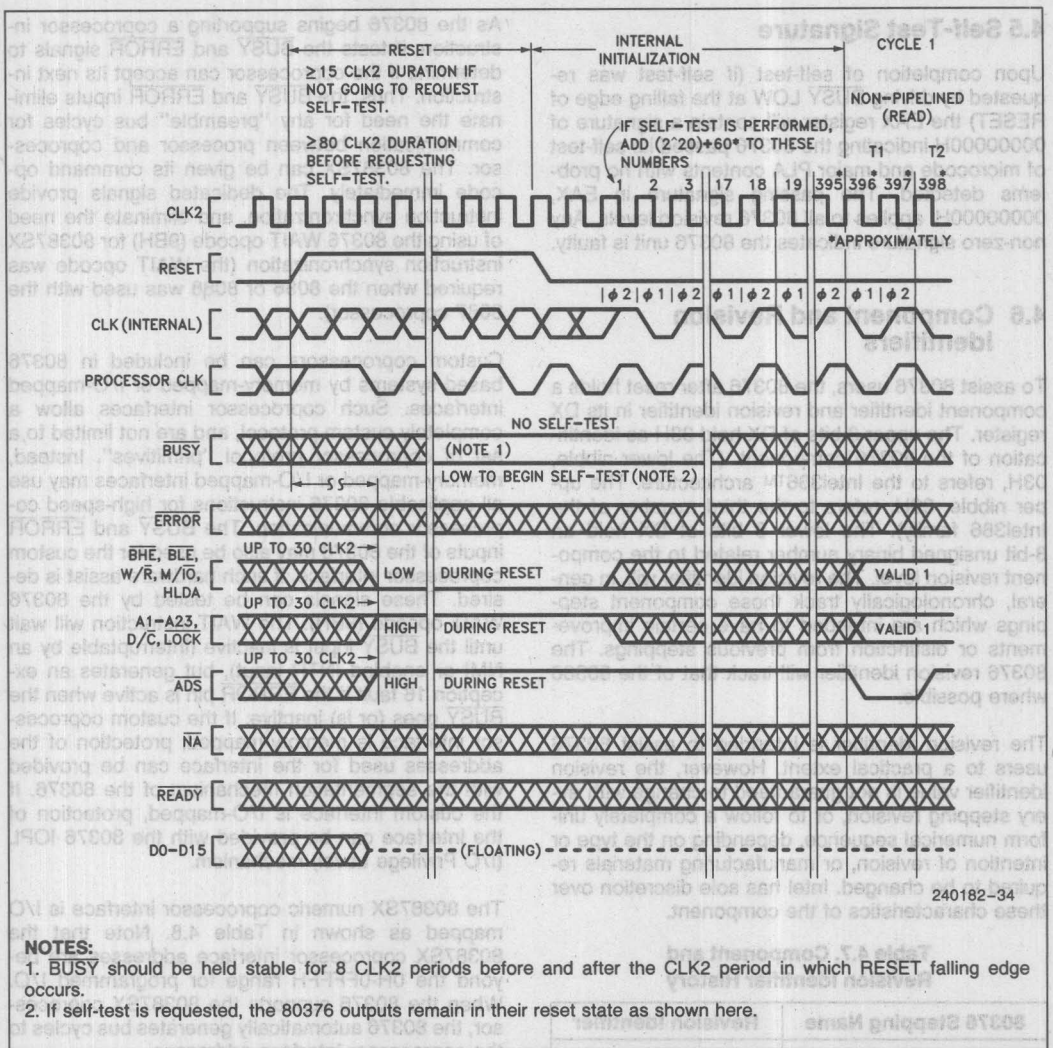


NOTE:
HOLD is a synchronous input and can be asserted at any CLK2 edge, provided setup and hold (t_{23} and t_{24}) requirements are met. This waveform is useful for determining Hold Acknowledge latency.

Figure 4.18. Requesting Hold from Idle Bus (NA Active)

An 80376 self-test may be requested at the time RESET goes inactive by having the BUSY input at a LOW level as shown in Figure 4.19. The self-test requires (2^{20} + approximately 60) CLK2 periods to complete. The self-test duration is not affected by the test results. Even if the self-test indicates a problem, the 80376 attempts to proceed with the reset sequence afterwards.

After the RESET falling edge (and after the self-test if it was requested) the 80376 performs an internal initialization sequence for approximately 350 to 450 CLK2 periods.



NOTES:
1. BUSY should be held stable for 8 CLK2 periods before and after the CLK2 period in which RESET falling edge occurs.
2. If self-test is requested, the 80376 outputs remain in their reset state as shown here.

Figure 4.19. Bus Activity from Reset until First Code Fetch

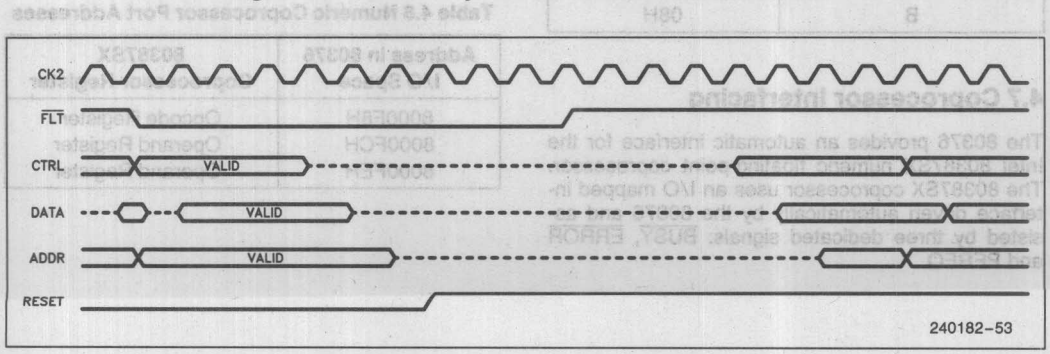


Figure 4.20. Entering and Exiting FLOAT

4.5 Self-Test Signature

Upon completion of self-test (if self-test was requested by driving BUSY LOW at the falling edge of RESET) the EAX register will contain a signature of 00000000H indicating the 80376 passed its self-test of microcode and major PLA contents with no problems detected. The passing signature in EAX, 00000000H, applies to all 80376 revision levels. Any non-zero signature indicates the 80376 unit is faulty.

4.6 Component and Revision Identifiers

To assist 80376 users, the 80376 after reset holds a component identifier and revision identifier in its DX register. The upper 8 bits of DX hold 33H as identification of the 80376 component. (The lower nibble, 03H, refers to the Intel386™ architecture. The upper nibble, 30H, refers to the third member of the Intel386 family). The lower 8 bits of DX hold an 8-bit unsigned binary number related to the component revision level. The revision identifier will, in general, chronologically track those component steppings which are intended to have certain improvements or distinction from previous steppings. The 80376 revision identifier will track that of the 80386 where possible.

The revision identifier is intended to assist 80376 users to a practical extent. However, the revision identifier value is not guaranteed to change with every stepping revision, or to follow a completely uniform numerical sequence, depending on the type or intention of revision, or manufacturing materials required to be changed. Intel has sole discretion over these characteristics of the component.

Table 4.7. Component and Revision Identifier History

80376 Stepping Name	Revision Identifier
A0	05H
B	08H

4.7 Coprocessor Interfacing

The 80376 provides an automatic interface for the Intel 80387SX numeric floating-point coprocessor. The 80387SX coprocessor uses an I/O mapped interface driven automatically by the 80376 and assisted by three dedicated signals: BUSY, ERROR and PEREQ.

As the 80376 begins supporting a coprocessor instruction, it tests the BUSY and ERROR signals to determine if the coprocessor can accept its next instruction. Thus, the BUSY and ERROR inputs eliminate the need for any "preamble" bus cycles for communication between processor and coprocessor. The 80387SX can be given its command opcode immediately. The dedicated signals provide instruction synchronization, and eliminate the need of using the 80376 WAIT opcode (9BH) for 80387SX instruction synchronization (the WAIT opcode was required when the 8086 or 8088 was used with the 8087 coprocessor).

Custom coprocessors can be included in 80376 based systems by memory-mapped or I/O-mapped interfaces. Such coprocessor interfaces allow a completely custom protocol, and are not limited to a set of coprocessor protocol "primitives". Instead, memory-mapped or I/O-mapped interfaces may use all applicable 80376 instructions for high-speed coprocessor communication. The BUSY and ERROR inputs of the 80376 may also be used for the custom coprocessor interface, if such hardware assist is desired. These signals can be tested by the 80376 WAIT opcode (9BH). The WAIT instruction will wait until the BUSY input is inactive (interruptable by an NMI or enabled INTR input), but generates an exception 16 fault if the ERROR pin is active when the BUSY goes (or is) inactive. If the custom coprocessor interface is memory-mapped, protection of the addresses used for the interface can be provided with the segmentation mechanism of the 80376. If the custom interface is I/O-mapped, protection of the interface can be provided with the 80376 IOPL (I/O Privilege Level) mechanism.

The 80387SX numeric coprocessor interface is I/O mapped as shown in Table 4.8. Note that the 80387SX coprocessor interface addresses are beyond the 0H-0FFFFH range for programmed I/O. When the 80376 supports the 80387SX coprocessor, the 80376 automatically generates bus cycles to the coprocessor interface addresses.

Table 4.8 Numeric Coprocessor Port Addresses

Address in 80376 I/O Space	80387SX Coprocessor Register
8000F8H	Opcode Register
8000FCH	Operand Register
8000FEH	Operand Register

SOFTWARE TESTING FOR COPROCESSOR PRESENCE

When software is used to test coprocessor (80387SX) presence, it should use only the following coprocessor opcodes: FNINIT, FNSTCW and FNSTSW. To use other coprocessor opcodes when a coprocessor is known to be not present, first set EM = 1 in the 80376 CR0 register.

5.0 PACKAGE THERMAL SPECIFICATIONS

The Intel 80376 embedded processor is specified for operation when case temperature is within the range of 0°C–115°C for both the ceramic 88-pin PGA package and the plastic 100-pin PQFP package. The case temperature may be measured in any environment, to determine whether the 80376 is within specified operating range. The case temperature should be measured at the center of the top surface.

The ambient temperature is guaranteed as long as T_c is not violated. The ambient temperature can be calculated from the θ_{jc} and θ_{ja} from the following equations:

$$T_J = T_c + P*\theta_{jc}$$

$$T_A = T_j - P*\theta_{ja}$$

$$T_C = T_a + P*[\theta_{ja} - \theta_{jc}]$$

Values for θ_{ja} and θ_{jc} are given in Table 5.1 for the 100-lead fine pitch. θ_{ja} is given at various airflows. Table 5.2 shows the maximum T_a allowable (without exceeding T_c) at various airflows. Note that T_a can be improved further by attaching "fins" or a "heat sink" to the package. P is calculated using the maximum ***cold*** I_{cc} of 305 mA and the maximum V_{CC} of 5.5V for both packages.

Table 5.1. 80376 Package Thermal Characteristics Thermal Resistances (°C/Watt) θ_{jc} and θ_{ja}

Package	θ_{jc}	θ_{ja} Versus Airflow-ft/min (m/sec)					
		0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
100-Lead Fine Pitch	7.5	34.5	29.5	25.5	22.5	21.5	21.0
88-Pin PGA	2.5	29.0	22.5	17.0	14.5	12.5	12.0

Table 5.2. 80376 Maximum Allowable Ambient Temperature at Various Airflows

Package	θ_{jc}	T_A(°C) vs Airflow-ft/min (m/sec)					
		0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
100-Lead Fine Pitch	7.5	70	78	85	90	92	93
88-Pin PGA	2.5	70	81	90	95	98	99

6.0 ELECTRICAL SPECIFICATIONS

The following sections describe recommended electrical connections for the 80376, and its electrical specifications.

6.1 Power and Grounding

The 80376 is implemented in CHMOS IV technology and has modest power requirements. However, its high clock frequency and 47 output buffers (address, data, control, and HLDA) can cause power surges as multiple output buffers drive new signal levels simultaneously. For clean on-chip power distribution at high frequency, 14 V_{CC} and 18 V_{SS} pins separately feed functional units of the 80376.

Power and ground connections must be made to all external V_{CC} and GND pins of the 80376. On the circuit board, all V_{CC} pins should be connected on a V_{CC} plane and all V_{SS} pins should be connected on a GND plane.

POWER DECOUPLING RECOMMENDATIONS

Liberal decoupling capacitors should be placed near the 80376. The 80376 driving its 24-bit address bus and 16-bit data bus at high frequencies can cause transient power surges, particularly when driving large capacitive loads. Low inductance capacitors and interconnects are recommended for best high frequency electrical performance. Inductance can be reduced by shortening circuit board traces between the 80376 and decoupling capacitors as much as possible.

RESISTOR RECOMMENDATIONS

The $\overline{\text{ERROR}}$, $\overline{\text{FLT}}$ and $\overline{\text{BUSY}}$ inputs have internal pull-up resistors of approximately 20 KΩ and the PEREQ input has an internal pull-down resistor of approximately 20 KΩ built into the 80376 to keep these signals inactive when the 80387SX is not present in the system (or temporarily removed from its socket).

9

In typical designs, the external pull-up resistors shown in Table 6.1 are recommended. However, a particular design may have reason to adjust the resistor values recommended here, or alter the use of pull-up resistors in other ways.

Table 6.1. Recommended Resistor Pull-Ups to V_{CC}

Pin	Signal	Pull-Up Value	Purpose
16	$\overline{ADS}$	20 KΩ ± 10%	Lightly Pull $\overline{ADS}$ Inactive during 80376 Hold Acknowledge States
26	$\overline{LOCK}$	20 KΩ ± 10%	Lightly Pull $\overline{LOCK}$ Inactive during 80376 Hold Acknowledge States

OTHER CONNECTION RECOMMENDATIONS

For reliable operation, always connect unused inputs to an appropriate signal level. N/C pins should always remain **unconnected. Connection of N/C pins to V_{CC} or V_{SS} will result in incompatibility with future steppings of the 80376.**

Particularly when not using interrupts or bus hold (as when first prototyping), prevent any chance of spurious activity by connecting these associated inputs to GND:

—INTR
—NMI
—HOLD

If not using address pipelining connect the $\overline{NA}$ pin to a pull-up resistor in the range of 20 KΩ to V_{CC}.

6.2 Absolute Maximum Ratings

Table 6.2. Maximum Ratings

Parameter	Maximum Rating
Storage Temperature	−65°C to +150°C
Case Temperature under Bias	−65°C to +120°C
Supply Voltage with Respect to V_{SS}	−0.5V to +6.5V
Voltage on Other Pins	−0.5V to (V_{CC} + 0.5)V

Table 6.2 gives a stress ratings only, and functional operation at the maximums is not guaranteed. Functional operating conditions are given in **Section 6.3, D.C. Specifications,** and **Section 6.4, A.C. Specifications.**

Extended exposure to the Maximum Ratings may affect device reliability. Furthermore, although the 80376 contains protective circuitry to resist damage from static electric discharge, always take precautions to avoid high static voltages or electric fields.

6.3 D.C. Specifications

ADVANCE INFORMATION SUBJECT TO CHANGE

Table 6.3: 80376 D.C. Characteristics

Functional Operating Range: V_{CC} = 5V ±10%; T_{CASE} = 0°C to 115°C for 88-pin PGA or 100-pin PQFP

Symbol	Parameter	Min	Max	Unit
V_{IL}	Input LOW Voltage	−0.3	+0.8	V(1)
V_{IH}	Input HIGH Voltage	2.0	V_{CC} +0.3	V(1)
V_{ILC}	CLK2 Input LOW Voltage	−0.3	+0.8	V(1)
V_{IHC}	CLK2 Input HIGH Voltage	V_{CC} − 0.8	V_{CC} + 0.3	V(1)
V_{OL}	Output LOW Voltage			
I_{OL} = 4 mA:	A_{23}–A_1, D_{15}–D_0		0.45	V(1)
I_{OL} = 5 mA:	$\overline{BHE}$, $\overline{BLE}$, W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{LOCK}$, $\overline{ADS}$, HLDA		0.45	V(1)
V_{OH}	Output High Voltage			
I_{OH} = −1 mA:	A_{23}–A_1, D_{15}–D_0	2.4		V(1)
I_{OH} = −0.2 mA:	A_{23}–A_1, D_{15}–D_0	V_{CC} − 0.5		V(1)
I_{OH} = −0.9 mA:	$\overline{BHE}$, $\overline{BLE}$, W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{LOCK}$, $\overline{ADS}$, HLDA	2.4		V(1)
I_{OH} = −0.18 mA:	$\overline{BHE}$, $\overline{BLE}$, W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{LOCK}$ $\overline{ADS}$, HLDA	V_{CC} − 0.5		V(1)
I_{LI}	Input Leakage Current (For All Pins except PEREQ, $\overline{BUSY}$, $\overline{FLT}$ and $\overline{ERROR}$)		±15	μA, 0V ≤ V_{IN} ≤ V_{CC}(1)
I_{IH}	Input Leakage Current (PEREQ Pin)		200	μA, V_{IH} = 2.4V(1, 2)
I_{IL}	Input Leakage Current ($\overline{BUSY}$ and $\overline{ERROR}$ Pins)		−400	μA, V_{IL} = 0.45V(3)
I_{LO}	Output Leakage Current		±15	μA, 0.45V ≤ V_{OUT} ≤ V_{CC}(1)
I_{CC}	Supply Current CLK2 = 32 MHz CLK2 = 40 MHz		 275 305	 mA, I_{CC} typ = 175 mA(4) mA, I_{CC} typ = 200 mA(4)
C_{IN}	Input Capacitance		10	pF, F_C = 1 MHz(5)
C_{OUT}	Output or I/O Capacitance		12	pF, F_C = 1 MHz(5)
C_{CLK}	CLK2 Capacitance		20	pF, F_C = 1 MHz(5)

NOTES:
1. Tested at the minimum operating frequency of the device.
2. PEREQ input has an internal pull-down resistor.
3. $\overline{BUSY}$, $\overline{FLT}$ and $\overline{ERROR}$ inputs each have an internal pull-up resistor.
4. I_{CC} max measurement at worse case load, V_{CC} and temperature (0°C).
5. Not 100% tested.

9

The A.C. specifications given in Table 6.4 consist of output delays, input setup requirements and input hold requirements. All A.C. specifications are relative to the CLK2 rising edge crossing the 2.0V level.

A.C. specification measurement is defined by Figure 6.1. Inputs must be driven to the voltage levels indicated by Figure 6.1 when A.C. specifications are measured. 80376 output delays are specified with minimum and maximum limits measured as shown. The minimum 80376 delay times are hold times provided to external circuitry. 80376 input setup and hold times are specified as minimums, defining the smallest acceptable sampling window. Within the sampling window, a synchronous input signal must be stable for correct 80376 processor operation.

Outputs $\overline{NA}$, W/$\overline{R}$, D/$\overline{C}$, M/$\overline{IO}$, $\overline{LOCK}$, $\overline{BHE}$, $\overline{BLE}$, A_{23}–A_1 and HLDA only change at the beginning of phase one. D_{15}–D_0 (write cycles) only change at the beginning of phase two. The $\overline{READY}$, HOLD, $\overline{BUSY}$, $\overline{ERROR}$, PEREQ and D_{15}–D_0 (read cycles) inputs are sampled at the beginning of phase one. The $\overline{NA}$, INTR and NMI inputs are sampled at the beginning of phase two.

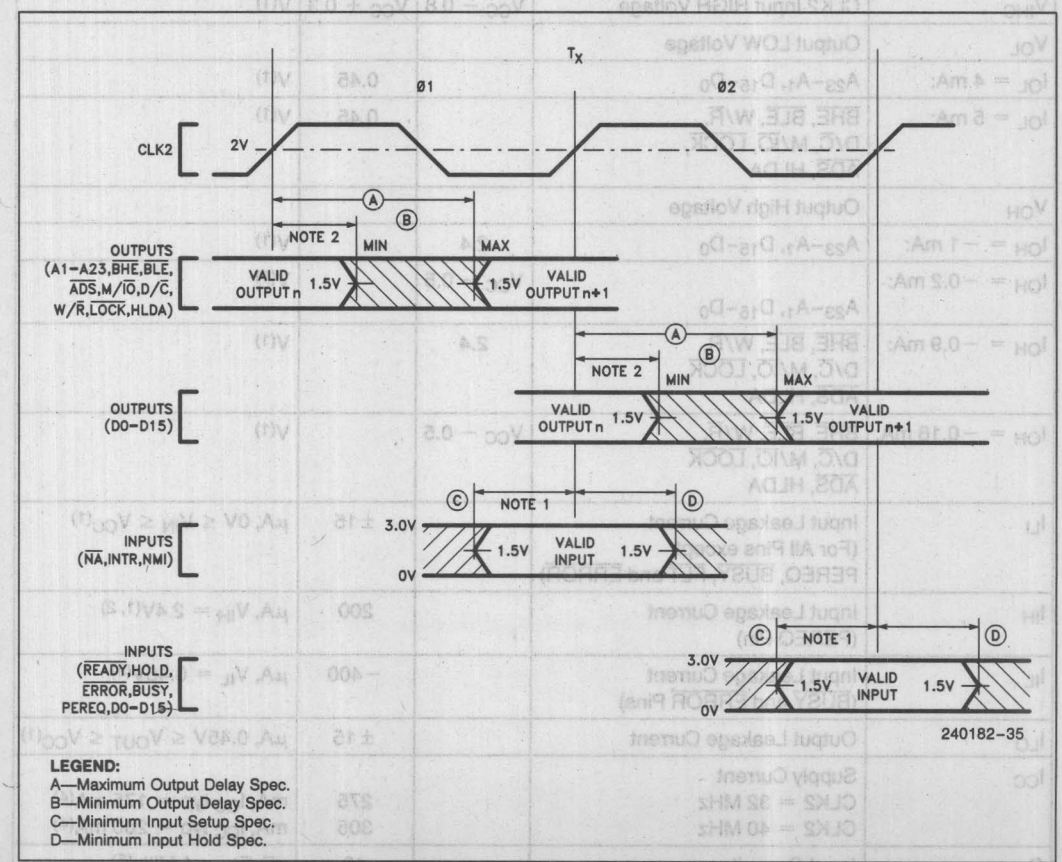


Figure 6.1. Drive Levels and Measurement Points for A.C. Specifications

6.4 A.C. Specifications

Table 6.4. 80376 A.C. Characteristics at 16 MHz

Functional Operating Range: V_{CC} = 5V ±10%; T_{CASE} = 0°C to 115°C for 88-pin PGA or 100-pin PQFP

Symbol	Parameter	Min	Max	Unit	Figure	Notes
	Operating Frequency	4	16	MHz		Half CLK2 Freq
t_1	CLK2 Period	31	125	ns	6.3	
t_{2a}	CLK2 HIGH Time	9		ns	6.3	At 2(3)
t_{2b}	CLK2 HIGH Time	5		ns	6.3	At (V_{CC} − 0.8)V(3)
t_{3a}	CLK2 LOW Time	9		ns	6.3	At 2V(3)
t_{3b}	CLK2 LOW Time	7		ns	6.3	At 0.8V(3)
t_4	CLK2 Fall Time		8	ns	6.3	(V_{CC}−0.8)V to 0.8V(3)
t_5	CLK2 Rise Time		8	ns	6.3	0.8V to (V_{CC}−0.8)(3)
t_6	A_{23}–A_1 Valid Delay	4	36	ns	6.5	C_L = 120 pF(4)
t_7	A_{23}–A_1 Float Delay	4	40	ns	6.6	(1)
t_8	$\overline{BHE}$, $\overline{BLE}$, $\overline{LOCK}$ Valid Delay	4	36	ns	6.5	C_L = 75 pF(4)
t_9	$\overline{BHE}$, $\overline{BLE}$, $\overline{LOCK}$ Float Delay	4	40	ns	6.6	(1)
t_{10}	W/$\overline{R}$, M/$\overline{IO}$, D/$\overline{C}$, $\overline{ADS}$ Valid Delay	6	33	ns	6.5	C_L = 75 pF(4)
t_{11}	W/$\overline{R}$, M/$\overline{IO}$, D/$\overline{C}$, $\overline{ADS}$ Float Delay	6	35	ns	6.6	(1)
t_{12}	D_{15}–D_0 Write Data Valid Delay	4	40	ns	6.5	C_L = 120 pF(4)
t_{13}	D_{15}–D_0 Write Data Float Delay	4	35	ns	6.6	(1)
t_{14}	HLDA Valid Delay	4	33	ns	6.6	C_L = 75 pF(4)
t_{15}	$\overline{NA}$ Setup Time	5		ns	6.4	
t_{16}	$\overline{NA}$ Hold Time	21		ns	6.6	
t_{19}	$\overline{READY}$ Setup Time	19		ns	6.4	
t_{20}	$\overline{READY}$ Hold Time	4		ns	6.4	
t_{21}	Setup Time D_{15}–D_0 Read Data	9		ns	6.4	
t_{22}	Hold Time D_{15}–D_0 Read Data	6		ns	6.4	
t_{23}	HOLD Setup Time	26		ns	6.4	
t_{24}	HOLD Hold Time	5		ns	6.4	
t_{25}	RESET Setup Time	13		ns	6.7	
t_{26}	RESET Hold Time	4		ns	6.7	

9

Table 6.4. 80376 A.C. Characteristics at 16 MHz (Continued)

Functional Operating Range: V_{CC} = 5V ±10%; T_{CASE} = 0°C to 115°C for 88-pin PGA or 100-pin PQFP

Symbol	Parameter	Min	Max	Unit	Figure	Notes
t_{27}	NMI, INTR Setup Time	16		ns	6.4	(2)
t_{28}	NMI, INTR Hold Time	16		ns	6.4	(2)
t_{29}	PEREQ, $\overline{ERROR}$, $\overline{BUSY}$, $\overline{FLT}$ Setup Time	16		ns	6.4	(2)
t_{30}	PEREQ, $\overline{ERROR}$, $\overline{BUSY}$, $\overline{FLT}$ Hold Time	5		ns	6.4	(2)

NOTES:
1. Float condition occurs when maximum output current becomes less than I_{LO} in magnitude. Float delay is not 100% tested.
2. These inputs are allowed to be asynchronous to CLK2. The setup and hold specifications are given for testing purposes, to assure recognition within a specific CLK2 period.
3. These are not tested. They are guaranteed by design characterization.
4. Tested with C_L set to 50 pF and derated to support the indicated distributed capacitive load. See Figures 6.8 through 6.10 for capacitive derating curves.
5. The 80376 does not have t_{17} or t_{18} timing specifications.

Table 6.5. 80376 A.C. Characteristics at 20 MHz

Functional Operating Range: V_{CC} = 5V ±10%; T_{CASE} = 0°C to 115°C for 88-pin PGA or 100-pin PQFP

Symbol	Parameter	Min	Max	Unit	Figure	Notes
	Operating Frequency	4	20	MHz		Half CLK2 Frequency
t_1	CLK2 Period	25	125	ns	6.3	
t_{2a}	CLK2 HIGH Time	8		ns	6.3	At 2V(3)
t_{2b}	CLK2 HIGH Time	5		ns	6.3	At (V_{CC} − 0.8)V(3)
t_{3a}	CLK2 LOW Time	8		ns	6.3	At 2V(3)
t_{3b}	CLK2 LOW Time	6		ns	6.3	At 0.8V(3)
t_4	CLK2 Fall Time		8	ns	6.3	(V_{CC}−0.8V) to 0.8V(3)
t_5	CLK2 Rise Time		8	ns	6.3	0.8V to (V_{CC}−0.8)(3)
t_6	A_{23}–A_1 Valid Delay	4	30	ns	6.5	C_L = 120 pF(4)
t_7	A_{23}–A_1 Float Delay	4		ns	6.6	(1)
t_8	$\overline{BHE}$, $\overline{BLE}$, $\overline{LOCK}$ Valid Delay	4	30	ns	6.5	C_L = 75 pF(4)
t_9	$\overline{BHE}$, $\overline{BLE}$, $\overline{LOCK}$ Float Delay	4	32	ns	6.6	(1)
t_{10a}	M/$\overline{IO}$, D/$\overline{C}$ Valid Delay	6	28	ns	6.5	C_L = 75 pF(4)
t_{10b}	W/$\overline{R}$, $\overline{ADS}$ Valid Delay	6	26	ns	6.5	C_L = 75 pF(4)
t_{11}	W/$\overline{R}$, M/$\overline{IO}$, D/$\overline{C}$, $\overline{ADS}$ Float Delay	6	30	ns	6.6	(1)
t_{12}	D_{15}–D_0 Write Data Valid Delay	4	38	ns	6.5	C_L = 120 pF
t_{13}	D_{15}–D_0 Write Data Float Delay	4	27	ns	6.6	(1)

Table 6.5. 80376 A.C. Characteristics at 20 MHz (Continued)
Functional Operating Range: V_{CC} = 5V ±10%; T_{CASE} = 0°C to 115°C for 88-pin PGA or 100-pin PQFP

Symbol	Parameter	Min	Max	Unit	Figure	Notes
t_{14}	HLDA Valid Delay	4	28	ns	6.5	C_L = 75 pF(4)
t_{15}	$\overline{NA}$ Setup Time	5		ns	6.4	
t_{16}	$\overline{NA}$ Hold Time	12		ns	6.4	
t_{19}	$\overline{READY}$ Setup Time	12		ns	6.4	
t_{20}	$\overline{READY}$ Hold Time	4		ns	6.4	
t_{21}	D_{15}–D_0 Read Data Setup Time	9		ns	6.4	
t_{22}	D_{15}–D_0 Read Data Hold Time	6		ns	6.4	
t_{23}	HOLD Setup Time	17		ns	6.4	
t_{24}	HOLD Hold Time	5		ns	6.4	
t_{25}	RESET Setup Time	12		ns	6.7	
t_{26}	RESET Hold Time	4		ns	6.7	
t_{27}	NMI, INTR Setup Time	16		ns	6.4	(2)
t_{28}	NMI, INTR Hold Time	16		ns	6.4	(2)
t_{29}	PEREQ, $\overline{ERROR}$, $\overline{BUSY}$, $\overline{FLT}$ Setup Time	14		ns	6.4	(2)
t_{30}	PEREQ, $\overline{ERROR}$, $\overline{BUSY}$, $\overline{FLT}$ Hold Time	5		ns	6.4	(2)

NOTES:
1. Float condition occurs when maximum output current becomes less than I_{LO} in magnitude. Float delay is not 100% tested.
2. These inputs are allowed to be asynchronous to CLK2. The setup and hold specifications are given for testing purposes, to assure recognition within a specific CLK2 period.
3. These are not tested. They are guaranteed by design characterization.
4. Tested with C_L set to 50 pF and derated to support the indicated distributed capacitive load. See Figures 6.8 through 6.10 for capacitive derating curves.
5. The 80376 does not have t_{17} or t_{18} timing specifications.

A.C. TEST LOADS

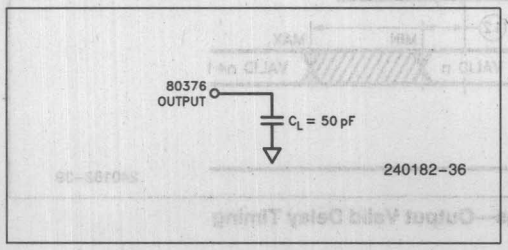


Figure 6.2. A.C. Test Loads

A.C. TIMING WAVEFORMS

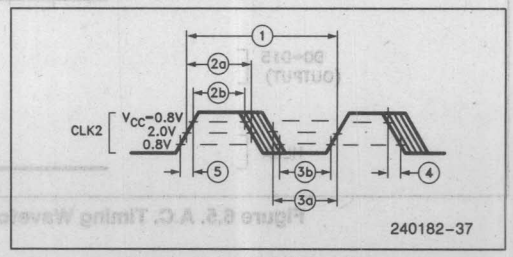


Figure 6.3. CLK2 Waveform

9

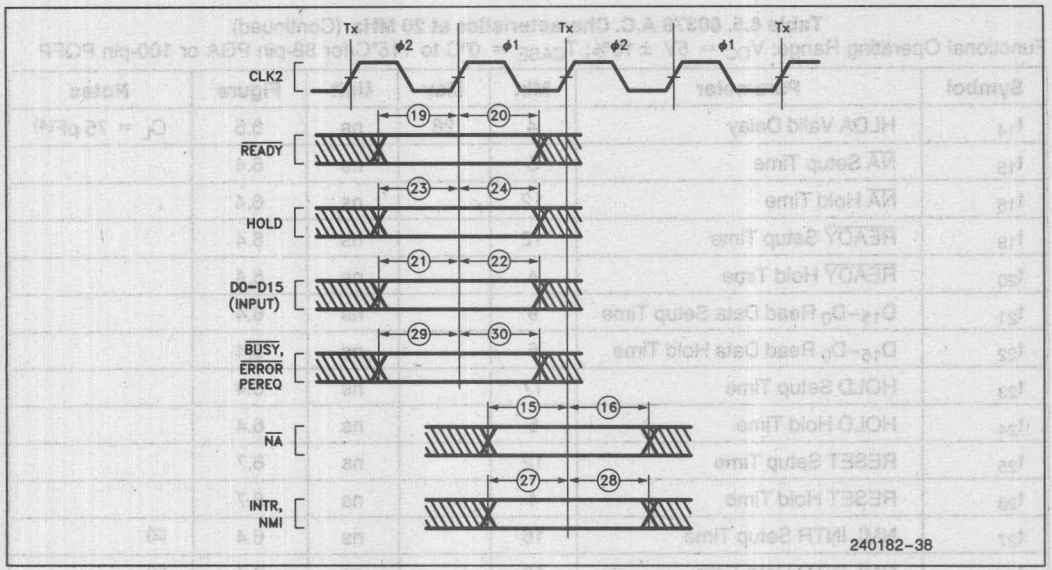


Figure 6.4. A.C. Timing Waveforms—Input Setup and Hold Timing

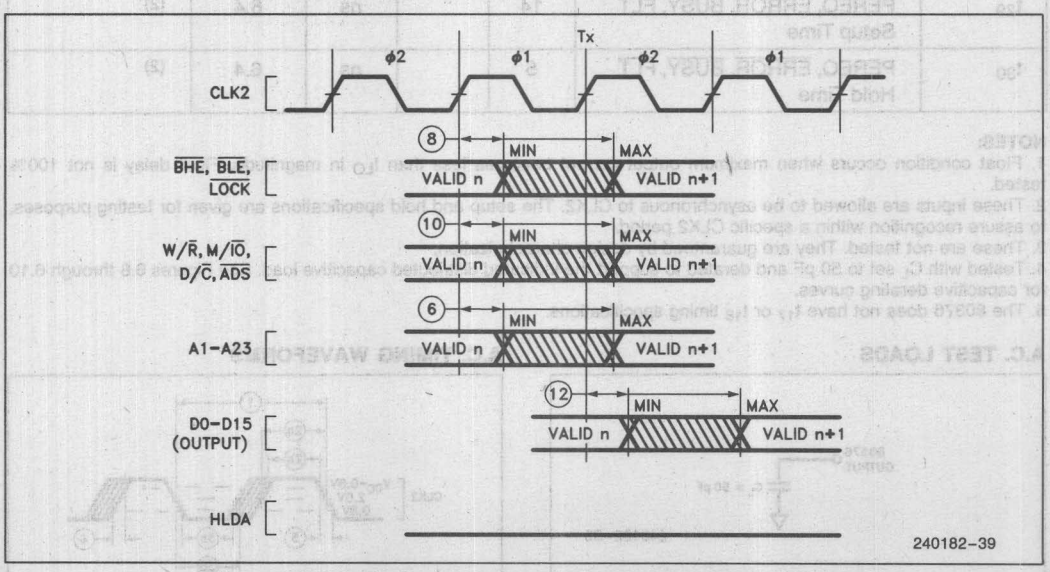


Figure 6.5. A.C. Timing Waveforms—Output Valid Delay Timing

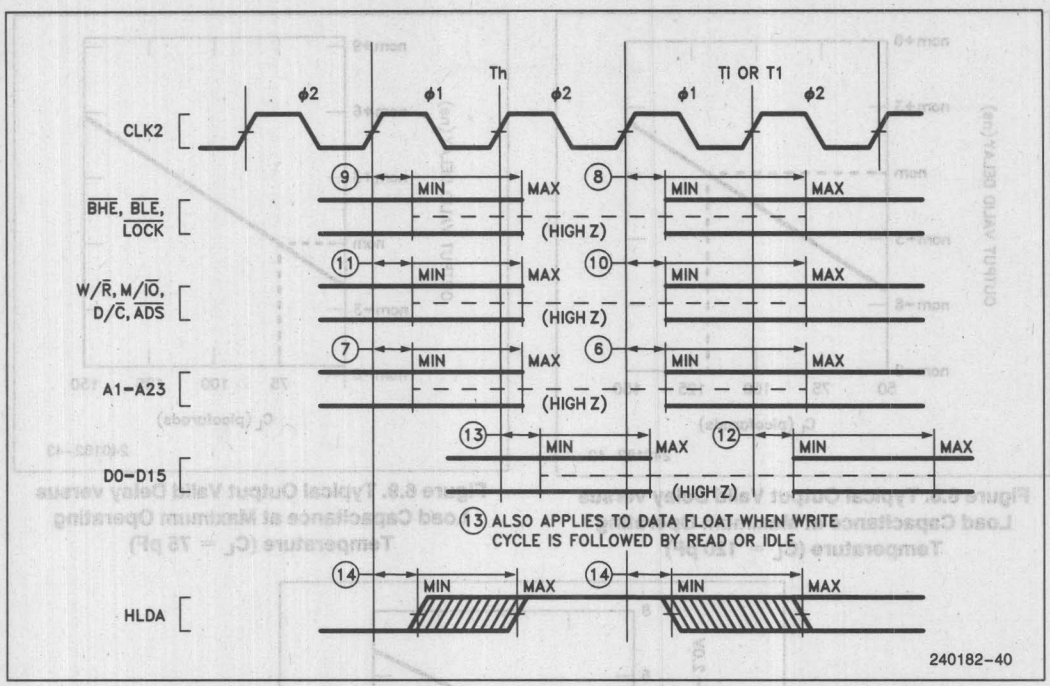
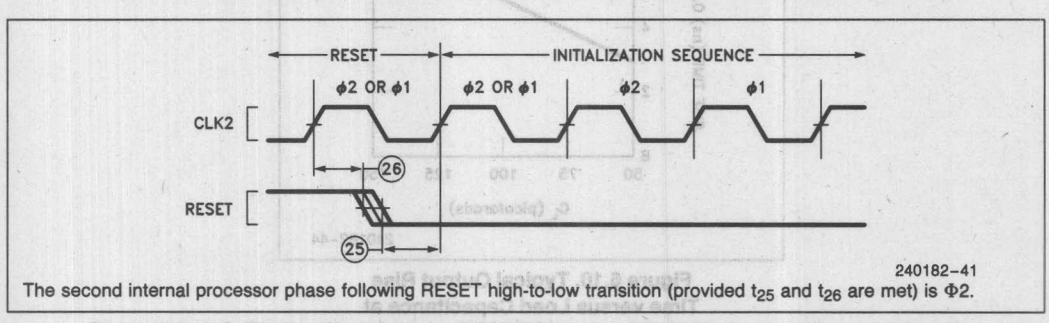


Figure 6.6. A.C. Timing Waveforms—Output Float Delay and HLDA Valid Delay Timing



The second internal processor phase following RESET high-to-low transition (provided t_{25} and t_{26} are met) is Φ2.

Figure 6.7. A.C. Timing Waveforms—RESET Setup and Hold Timing, and Internal Phase

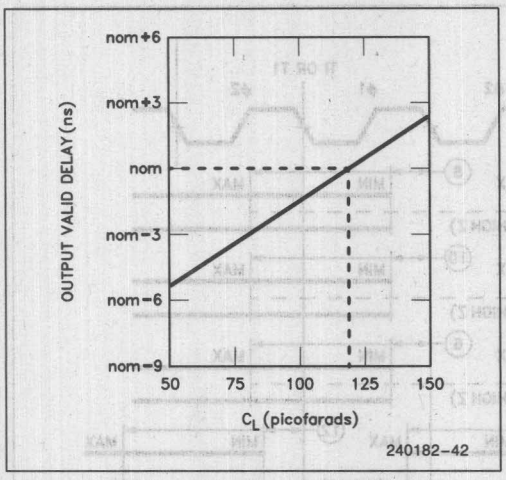


Figure 6.8. Typical Output Valid Delay versus Load Capacitance at Maximum Operating Temperature (C_L = 120 pF)

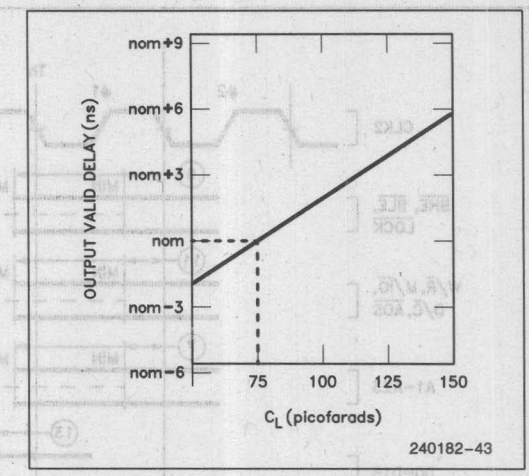


Figure 6.9. Typical Output Valid Delay versus Load Capacitance at Maximum Operating Temperature (C_L = 75 pF)

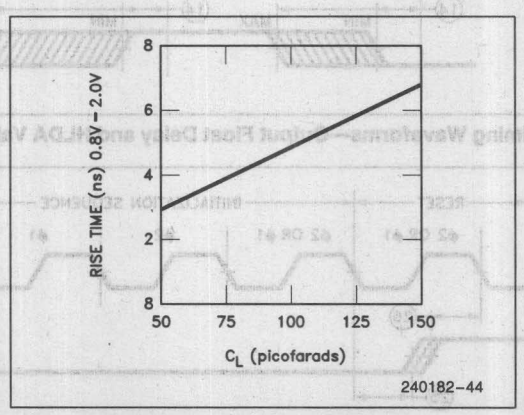


Figure 6.10. Typical Output Rise Time versus Load Capacitance at Maximum Operating Temperature

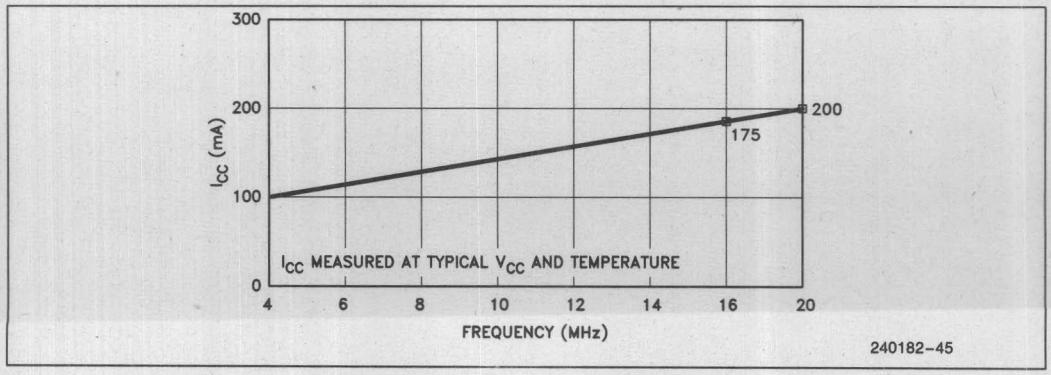


Figure 6.11. Typical I_{CC} vs Frequency

6.5 Designing for the ICE™-376 Emulator

The 376 embedded processor in-circuit emulator product is the ICE-376 emulator. Use of the emulator requires the target system to provide a socket that is compatible with the ICE-376 emulator. The 80376 offers two different probes for emulating user systems: an 88-pin PGA probe and a 100-pin fine pitch flat-pack probe. The 100-pin fine pitch flat-pack probe requires a socket, called the 100-pin PQFP, which is available from 3-M Textool (part number 2-0100-07243-000). The ICE-376 emulator probe attaches to the target system via an adapter which replaces the 80376 component in the target system. Because of the high operating frequency of 80376 systems and of the ICE-376 emulator, there is no buffering between the 80376 emulation processor in the ICE-376 emulator probe and the target system. A direct result of the non-buffered interconnect is that the ICE-376 emulator shares the address and data bus with the user's system, and the RESET signal is intercepted by the ICE emulator hardware. In order for the ICE-376 emulator to be functional in the user's system without the Optional Isolation Board (OIB) the designer must be aware of the following conditions:

1. The bus controller must only enable data transceivers onto the data bus during valid read cycles of the 80376, other local devices or other bus masters.
2. Before another bus master drives the local processor address bus, the other master must gain control of the address bus by asserting HOLD and receiving the HLDA response.
3. The emulation processor receives the RESET signal 2 or 4 CLK2 cycles later than an 80376 would, and responds to RESET later. Correct phase of the response is guaranteed.

In addition to the above considerations, the ICE-376 emulator processor module has several electrical and mechanical characteristics that should be taken into consideration when designing the 80376 system.

Capacitive Loading: ICE-376 adds up to 27 pF to each 80376 signal.

Drive Requirements: ICE-376 adds one FAST TTL load on the CLK2, control, address, and data lines. These loads are within the processor module and are driven by the 80376 emulation processor, which has standard drive and loading capability listed in Tables 6.3 and 6.4.

Power Requirements: For noise immunity and CMOS latch-up protection the ICE-376 emulator processor module is powered by the user system. The circuitry on the processor module draws up to 1.4A including the maximum 80376 I_{CC} from the user 80376 socket.

80376 Location and Orientation: The ICE-376 emulator processor module may require lateral clearance. Figure 6.12 shows the clearance requirements of the iMP adapter and Figure 6.13 shows the clearance requirements of the 88-pin PGA adapter. The

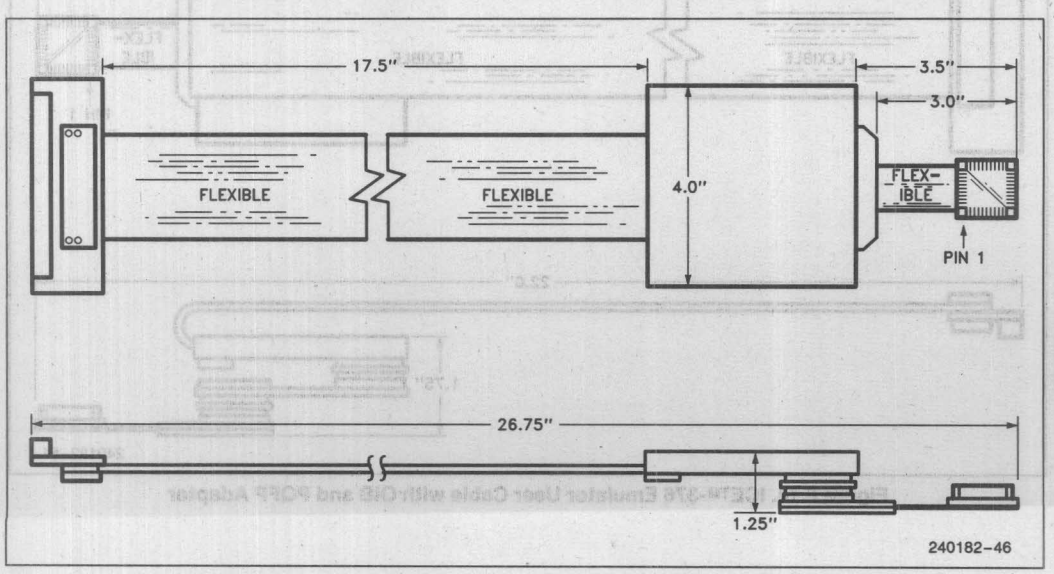


Figure 6.12. Preliminary ICE™-376 Emulator User Cable with PQFP Adapter

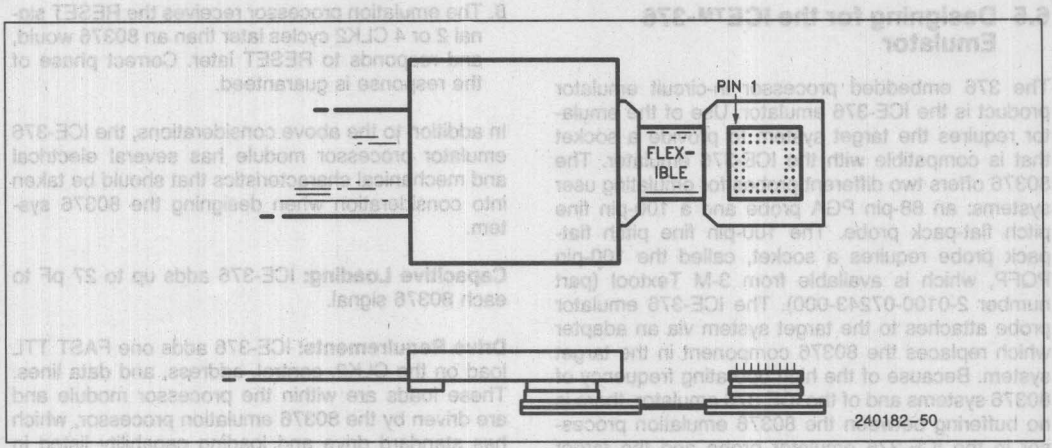


Figure 6.13. ICE™-376 Emulator User Cable with 88-Pin PGA Adapter

optional isolation board (OIB), which provides extra electrical buffering and has the same lateral clearance requirements as Figures 6.12 and 6.13, adds an additional 0.5 inches to the vertical clearance requirement. This is illustrated in Figure 6.14.

Optional Isolation Board (OIB) and the CLK2 speed reduction: Due to the unbuffered probe design, the ICE-376 emulator is susceptible to errors on the user's bus. The OIB allows the ICE-376 emulator to function in user systems with faults (shorted signals, etc.). After electrical verification the OIB may be removed. When the OIB is installed, the user system must have a maximum CLK2 frequency of 20 MHz.

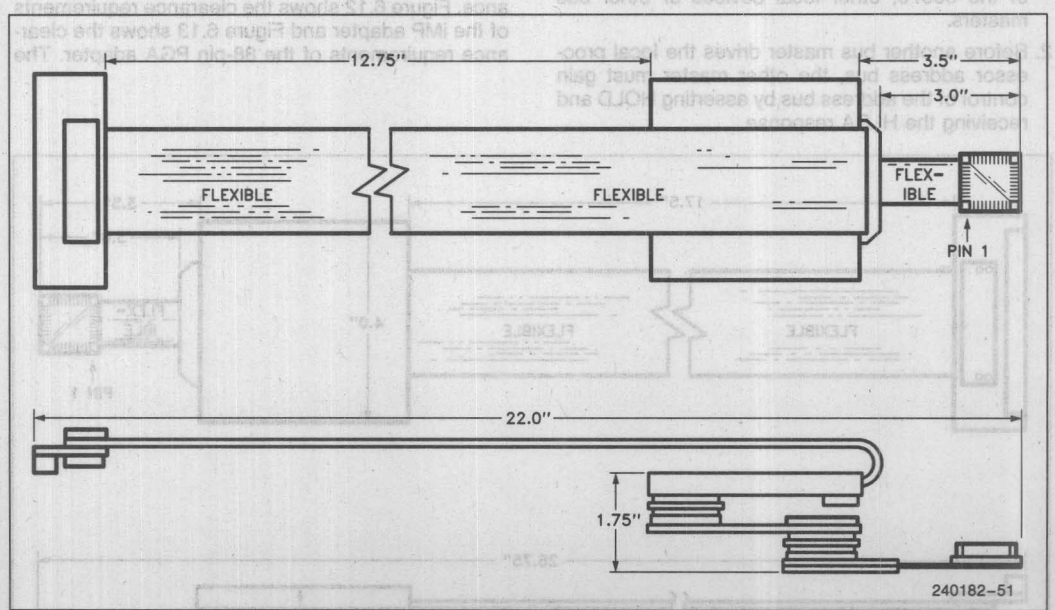


Figure 6.14. ICE™-376 Emulator User Cable with OIB and PQFP Adapter

7.0 DIFFERENCES BETWEEN THE 80376 AND THE 80386

The following are the major differences between the 80376 and the 80386.

1. The 80376 generates byte selects on $\overline{BHE}$ and $\overline{BLE}$ (like the 8086 and 80286 microprocessors) to distinguish the upper and lower bytes on its 16-bit data bus. The 80386 uses four-byte selects, $\overline{BE0}$–$\overline{BE3}$, to distinguish between the different bytes on its 32-bit bus.
2. The 80376 has no bus sizing option. The 80386 can select between either a 32-bit bus or a 16-bit bus by use of the $\overline{BS16}$ input. The 80376 has a 16-bit bus size.
3. The $\overline{NA}$ pin operation in the 80376 is identical to that of the $\overline{NA}$ pin on the 80386 with one exception: the $\overline{NA}$ pin of the 80386 cannot be activated on 16-bit bus cycles (where $\overline{BS16}$ is LOW in the 80386 case), whereas $\overline{NA}$ can be activated on any 80376 bus cycle.
4. The contents of all 80376 registers at reset are identical to the contents of the 80386 registers at reset, except the DX register. The DX register contains a component-stepping identifier at reset, i.e.

   in 80386, after reset DH = 03H indicates 80386
   DL = revision number;
   in 80376, after reset DH = 33H indicates 80376
   DL = revision number.

5. The 80386 uses A_{31} and M/$\overline{IO}$ as a select for numerics coprocessor. The 80376 uses the A_{23} and M/$\overline{IO}$ to select its numerics coprocessor.
6. The 80386 prefetch unit fetches code in four-byte units. The 80376 prefetch unit reads two bytes as one unit (like the 80286 microprocessor). In $\overline{BS16}$ mode, the 80386 takes two consecutive bus cycles to complete a prefetch request. If there is a data read or write request after the prefetch starts, the 80386 will fetch all four bytes before addressing the new request.
7. The 80376 has no paging mechanism.
8. The 80376 starts executing code in what corresponds to the 80386 protected mode. The 80386 starts execution in real mode, which is then used to enter protected mode.
9. The 80386 has a virtual-86 mode that allows the execution of a real mode 8086 program as a task in protected mode. The 80376 has no virtual-86 mode.
10. The 80386 maps a 48-bit logical address into a 32-bit physical address by segmentation and paging. The 80376 maps its 48-bit logical address into a 24-bit physical address by segmentation only.
11. The 80376 uses the 80387SX numerics coprocessor for floating point operations, while the 80386 uses the 80387 coprocessor.
12. The 80386 can execute from 16-bit code segments. The 80376 can **only** execute from 32-bit code Segments.
13. The 80376 has an input called $\overline{FLT}$ which three-states all bidirectional and output pins, including HLDA, when asserted. It is used with ON Circuit Emulation (ONCE).

8.0 INSTRUCTION SET

This section describes the 376 embedded processor instruction set. Table 8.1 lists all instructions along with instruction encoding diagrams and clock counts. Further details of the instruction encoding are then provided in the following sections, which completely describe the encoding structure and the definition of all fields occurring within 80376 instructions.

8.1 80376 Instruction Encoding and Clock Count Summary

To calculate elapsed time for an instruction, multiply the instruction clock count, as listed in Table 8.1 below, by the processor clock period (e.g. 50 ns for an 80376 operating at 20 MHz). The actual clock count of an 80376 program will average 10% more

9

than the calculated clock count due to instruction sequences which execute faster than they can be fetched from memory.

Instruction Clock Count Assumptions:

1. The instruction has been prefetched, decoded, and is ready for execution.
2. Bus cycles do not require wait states.
3. There are no local bus HOLD requests delaying processor acess to the bus.
4. No exceptions are detected during instruction execution.
5. If an effective address is calculated, it does not use two general register components. One register scaling and displacement can be used within the clock counts showns. However, if the effective address calculation uses two general register components, add 1 clock to the clock count shown.
6. Memory reference instruction accesses byte or aligned 16-bit operands.

Instruction Clock Count Notation

— If two clock counts are given, the smaller refers to a register operand and the larger refers to a memory operand.

—n = number of times repeated.

—m = number of components in the next instruction executed, where the entire displacement (if any) counts as one component, the entire immediate data (if any) counts as one component, and all other bytes of the instruction and prefix(es) each count as one component.

Misaligned or 32-Bit Operand Accesses:

— If instructions accesses a misaligned 16-bit operand or 32-bit operand on even address add:

2* clocks for read or write.

4** clocks for read and write.

— If instructions accesses a 32-bit operand on odd address add:

4* clocks for read or write.

8** clocks for read and write.

Wait States:

Wait states add 1 clock per wait state to instruction execution for each data access.

Table 8.1. 80376 Instruction Set Clock Count Summary

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
GENERAL DATA TRANSFER				
MOV = Move:				
Register to Register/Memory	1000100w mod reg r/m	2/2*	0/1*	a
Register/Memory to Register	1000101w mod reg r/m	2/4*	0/1*	a
Immediate to Register/Memory	1100011w mod 000 r/m immediate data	2/2*	0/1*	a
Immediate to Register (Short Form)	1011 w reg immediate data	2	2	
Memory to Accumulator (Short Form)	1010000w full displacement	4*	1*	a
Accumulator to Memory (Short Form)	1010001w full displacement	2*	1*	a
Register/Memory to Segment Register	10001110 mod sreg3 r/m	22/23*	0/6*	a,b,c
Segment Register to Register/Memory	10001100 mod sreg3 r/m	2/2*	0/1*	a
MOVSX = Move with Sign Extension				
Register from Register/Memory	00001111 1011111w mod reg r/m	3/6*	0/1*	a
MOVZX = Move with Zero Extension				
Register from Register/Memory	00001111 1011011w mod reg r/m	3/6*	0/1*	a
PUSH = Push:				
Register/Memory	11111111 mod 110 r/m	7/9*	2/4*	a
Register (Short Form)	01010 reg	4	2	a
Segment Register (ES, CS, SS or DS)	000sreg2 110	4	2	a
Segment Register (FS or GS)	00001111 10 sreg3 000	4	2	a
Immediate	011010s0 immediate data	4	2	a
PUSHA = Push All	01100000	34	16	a
POP = Pop				
Register/Memory	10001111 mod 000 r/m	7/9*	2/4*	a
Register (Short Form)	01011 reg	6	2	a
Segment Register (ES, SS or DS)	000 sreg 2 111	25	6	a, b, c
Segment Register (FS or GS)	00001111 10 sreg 3 001	25	6	a, b, c
POPA = Pop All	01100001	40	16	a
XCHG = Exchange				
Register/Memory with Register	1000011w mod reg r/m	3/5**	0/2**	a, m
Register with Accumulator (Short Form)	10010 reg	3	0	
IN = Input from:				
Fixed Port	1110010w port number	6*	1*	f,k
		26*	1*	f,l
Variable Port	1110110w	7*	1*	f,k
		27*	1*	f,l
OUT = Output to:				
Fixed Port	1110011w port number	4*	1*	f,k
		24*	1*	f,l
Variable Port	1110111w	5*	1*	f,k
		26*	1*	f,l
LEA = Load EA to Register	10001101 mod reg r/m	2		

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
SEGMENT CONTROL				
LDS = Load Pointer to DS	11000101 | mod reg r/m	26*	6*	a, b, c
LES = Load Pointer to ES	11000100 | mod reg r/m	26*	6*	a, b, c
LFS = Load Pointer to FS	00001111 | 10110100 | mod reg r/m	29*	6*	a, b, c
LGS = Load Pointer to GS	00001111 | 10110101 | mod reg r/m	29*	6*	a, b, c
LSS = Load Pointer to SS	00001111 | 10110010 | mod reg r/m	26*	6*	a, b, c
FLAG CONTROL				
CLC = Clear Carry Flag	11111000	2		
CLD = Clear Direction Flag	11111100	2		
CLI = Clear Interrupt Enable Flag	11111010	8		f
CLTS = Clear Task Switched Flag	00001111 | 00000110	5		e
CMC = Complement Carry Flag	11110101	2		
LAHF = Load AH into Flag	10011111	2		
POPF = Pop Flags	10011101	7		a, g
PUSHF = Push Flags	10011100	4		a
SAHF = Store AH into Flags	10011110	3		
STC = Set Carry Flag	11111001	2		
STD = Set Direction Flag	11111101	2		
STI = Set Interrupt Enable Flag	11111011	8		f
ARITHMETIC				
ADD = Add				
Register to Register	000000dw | mod reg r/m	2		
Register to Memory	0000000w | mod reg r/m	7**	2**	a
Memory to Register	0000001w | mod reg r/m	6*	1*	a
Immediate to Register/Memory	100000sw | mod 000 r/m | immediate data	2/7**	0/2**	a
Immediate to Accumulator (Short Form)	0000010w | immediate data	2		
ADC = Add with Carry				
Register to Register	000100dw | mod reg r/m	2		
Register to Memory	0001000w | mod reg r/m	7**	2**	a
Memory to Register	0001001w | mod reg r/m	6*	1*	a
Immediate to Register/Memory	100000sw | mod 010 r/m | immediate data	2/7**	0/2**	a
Immediate to Accumulator (Short Form)	0001010w | immediate data	2		
INC = Increment				
Register/Memory	1111111w | mod 000 r/m	2/6**	0/2**	a
Register (Short Form)	01000 | reg	2		
SUB = Subtract				
Register from Register	001010dw | mod reg r/m	2		

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number Of Data Cycles	Notes
ARITHMETIC (Continued)				
Register from Memory	0010100w mod reg r/m	7**	2**	a
Memory from Register	0010101w mod reg r/m	6*	1	a
Immediate from Register/Memory	100000sw mod 101 r/m immediate data	2/7**	0/1**	a
Immediate from Accumulator (Short Form)	0010110w immediate data	2		
SBB = Subtract with Borrow				
Register from Register	000110dw mod reg r/m	2		
Register from Memory	0001100w mod reg r/m	7**	2**	a
Memory from Register	0001101w mod reg r/m	6*	1*	a
Immediate from Register/Memory	100000sw mod 011 r/m immediate data	2/7**	0/2**	a
Immediate from Accumulator (Short Form)	0001110w immediate data	2		
DEC = Decrement				
Register/Memory	1111111w reg 001 r/m	2/6**	0/2**	a
Register (Short Form)	01001 reg	2		
CMP = Compare				
Register with Register	001110dw mod reg r/m	2		
Memory with Register	0011100w mod reg r/m	5*	1*	a
Register with Memory	0011101w mod reg r/m	6**	2**	a
Immediate with Register/Memory	100000sw mod 111 r/m immediate data	2/5*	0/1*	a
Immediate with Accumulator (Short Form)	0011110w immediate data	2		
NEG = Change Sign	1111011w mod 011 r/m	2/6*	0/2*	a
AAA = ASCII Adjust for Add	00110111	4		
AAS = ASCII Adjust for Subtract	00111111	4		
DAA = Decimal Adjust for Add	00100111	4		
DAS = Decimal Adjust for Subtract	00101111	4		
MUL = Multiply (Unsigned)				
Accumulator with Register/Memory	1111011w mod 100 r/m			
Multiplier—Byte		12–17/15–20	0/1	a,n
—Word		12–25/15–28*	0/1*	a,n
—Doubleword		12–41/17–46*	0/2*	a,n
IMUL = Integer Multiply (Signed)				
Accumulator with Register/Memory	1111011w mod 101 r/m			
Multiplier—Byte		12–17/15–20	0/1	a,n
—Word		12–25/15–28*	0/1*	a,n
—Doubleword		12–41/17–46*	0/2*	a,n
Register with Register/Memory	00001111 10101111 mod reg r/m			
Multiplier—Byte		12–17/15–20	0/1	a,n
—Word		12–25/15–28*	0/1*	a,n
—Doubleword		12–41/17–46*	0/2*	a,n
Register/Memory with Immediate to Register	011010s1 mod reg r/m immediate data			
—Word		13–26/14–27*	0/1*	a,n
—Doubleword		13–42/16–45*	0/2*	a,n

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number Of Data Cycles	Notes
ARITHMETIC (Continued)				
DIV = Divide (Unsigned)				
Accumulator by Register/Memory	1111011w mod110 r/m			
Divisor—Byte		14/17	0/1	a, o
—Word		22/25*	0/1*	a, o
—Doubleword		38/43*	0/2*	a, o
IDIV = Integer Divide (Signed)				
Accumulator by Register/Memory	1111011w mod111 r/m			
Divisor—Byte		19/22	0/1	a, o
—Word		27/30*	0/1	a, o
—Doubleword		43/48*	0/2*	a, o
AAD = ASCII Adjust for Divide	11010101 00001010	19		
AAM = ASCII Adjust for Multiply	11010100 00001010	17		
CBW = Convert Byte to Word	10011000	3		
CWD = Convert Word to Double Word	10011001	2		
LOGIC				
Shift Rotate Instructions				
Not Through Carry **(ROL, ROR, SAL, SAR, SHL,** and **SHR)**				
Register/Memory by 1	1101000w mod TTT r/m	3/7**	0/2**	a
Register/Memory by CL	1101001w mod TTT r/m	3/7**	0/2**	a
Register/Memory by Immediate Count	1100000w mod TTT r/m immed 8-bit data	3/7**	0/2**	a
Through Carry **(RCL** and **RCR)**				
Register/Memory by 1	1101000w mod TTT r/m	9/10**	0/2**	a
Register/Memory by CL	1101001w mod TTT r/m	9/10**	10/2**	a
Register/Memory by Immediate Count	1100000w mod TTT r/m immed 8-bit data	9/10**	0/2**	a
	TTT Instruction: 000 ROL; 001 ROR; 010 RCL; 011 RCR; 100 SHL/SAL; 101 SHR; 111 SAR			
SHLD = Shift Left Double				
Register/Memory by Immediate	00001111 10100100 mod reg r/m immed 8-bit data	3/7**	0/2**	
Register/Memory by CL	00001111 10100101 mod reg r/m	3/7**	0/2**	
SHRD = Shift Right Double				
Register/Memory by Immediate	00001111 10101100 mod reg r/m immed 8-bit data	3/7**	0/2**	
Register/Memory by CL	00001111 10101101 mod reg r/m	3/7**	0/2**	
AND = And				
Register to Register	001000dw mod reg r/m	2		

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
LOGIC (Continued)				
Register to Memory	0010000w mod reg r/m	7**	2**	a
Memory to Register	0010001w mod reg r/m	6*	1*	a
Immediate to Register/Memory	1000000w mod 100 r/m immediate data	2/7**	0/2**	a
Immediate to Accumulator (Short Form)	0010010w immediate data	2		
TEST = And Function to Flags, No Result				
Register/Memory and Register	1000010w mod reg r/m	2/5*	0/1*	a
Immediate Data and Register/Memory	1111011w mod 000 r/m immediate data	2/5*	0/1*	a
Immediate Data and Accumulator (Short Form)	1010100w immediate data	2		
OR = Or				
Register to Register	000010dw mod reg r/m	2		
Register to Memory	0000100w mod reg r/m	7**	2**	a
Memory to Register	0000101w mod reg r/m	6*	1*	a
Immediate to Register/Memory	1000000w mod 001 r/m immediate data	2/7**	0/2**	a
Immediate to Accumulator (Short Form)	0000110w immediate data	2		
XOR = Exclusive Or				
Register to Register	001100dw mod reg r/m	2		
Register to Memory	0011000w mod reg r/m	7**	2**	a
Memory to Register	0011001w mod reg r/m	6*	1*	a
Immediate to Register/Memory	1000000w mod 110 r/m immediate data	2/7**	0/2**	a
Immediate to Accumulator (Short Form)	0011010w immediate data	2		
NOT = Invert Register/Memory	1111011w mod 010 r/m	2/6**	0/2**	a
STRING MANIPULATION				
CMPS = Compare Byte Word	1010011w	10*	2*	a
INS = Input Byte/Word from DX Port	0110110w	9**	1**	a,f,k
		29**	1**	a,f,l
LODS = Load Byte/Word to AL/AX/EAX	1010110w	5*	1*	a
MOVS = Move Byte Word	1010010w	7**	2**	a
OUTS = Output Byte/Word to DX Port	0110111w	8**	1**	a,f,k
		28**	1**	a,f,l
SCAS = Scan Byte Word	1010111w	7*	1*	a
STOS = Store Byte/Word from AL/AX/EX	1010101w	4*	1*	a
XLAT = Translate String	11010111	5*	1*	a
REPEATED STRING MANIPULATION Repeated by Count in CX or ECX				
REPE CMPS = Compare String (Find Non-Match)	11110011 1010011w	5 + 9n**	2n**	a

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
REPEATED STRING MANIPULATION (Continued)				
REPNE CMPS = Compare String				
(Find Match)	11110010 1010011w	5 + 9n**	2n**	a
REP INS = Input String	11110011 0110110w	7 + 6n*	1n*	a,f,k
		27 + 6n*	1n*	a,f,l
REP LODS = Load String	11110011 1010110w	5 + 6n*	1n*	a
REP MOVS = Move String	11110011 1010010w	7 + 4n**	2n**	a
REP OUTS = Output String	11110011 0110111w	6 + 5n*	1n*	a,f,k
		26 + 5n*	1n*	a,f,l
REPE SCAS = Scan String				
(Find Non-AL/AX/EAX)	11110011 1010111w	5 + 8n*	1n*	a
REPNE SCAS = Scan String				
(Find AL/AX/EAX)	11110010 1010111w	5 + 8n*	1n*	a
REP STOS = Store String	11110011 1010101w	5 + 5n*	1n*	a
BIT MANIPULATION				
BSF = Scan Bit Forward	00001111 10111100 mod reg r/m	10 + 3n**	2n**	a
BSR = Scan Bit Reverse	00001111 10111101 mod reg r/m	10 + 3n**	2n**	a
BT = Test Bit				
Register/Memory, Immediate	00001111 10111010 mod 100 r/m immed 8-bit data	3/6*	0/1*	a
Register/Memory, Register	00001111 10100011 mod reg r/m	3/12*	0/1*	a
BTC = Test Bit and Complement				
Register/Memory, Immediate	00001111 10111010 mod 111 r/m immed 8-bit data	6/8*	0/2*	a
Register/Memory, Register	00001111 10111011 mod reg r/m	6/13*	0/2*	a
BTR = Test Bit and Reset				
Register/Memory, Immediate	00001111 10111010 mod 110 r/m immed 8-bit data	6/8*	0/2*	a
Register/Memory, Register	00001111 10110011 mod reg r/m	6/13*	0/2*	a
BTS = Test Bit and Set				
Register/Memory, Immediate	00001111 10111010 mod 101 r/m immed 8-bit data	6/8*	0/2*	a
Register/Memory, Register	00001111 10101011 mod reg r/m	6/13*	0/2*	a
CONTROL TRANSFER				
CALL = Call				
Direct within Segment	11101000 full displacement	9 + m*	2	j
Register/Memory				
Indirect within Segment	11111111 mod 010 r/m	9 + m/12 + m	2/3	a, j
Direct Intersegment	10011010 unsigned full offset, selector	42 + m	9	c, d, j

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
CONTROL TRANSFER (Continued)				
(Direct Intersegment)				
Via Call Gate to Same Privilege Level		64 + m	13	a,c,d,j
Via Call Gate to Different Privilege Level, (No Parameters)		98 + m	13	a,c,d,j
Via Call Gate to Different Privilege Level, (x Parameters)		106 + 8x + m	13 + 4x	a,c,d,j
From 386 Task to 386 TSS		392	124	a,c,d,j
Indirect Intersegment	11111111 mod011 r/m	46 + m	10	a,c,d,j
Via Call Gate to Same Privilege Level		68 + m	14	a,c,d,j
Via Call Gate to Different Privilege Level, (No Parameters)		102 + m	14	a,c,d,j
Via Call Gate to Different Privilege Level, (x Parameters)		110 + 8x + m	14 + 4x	a,c,d,j
From 386 Task to 386 TSS		399	130	a,c,d,j
JMP = Unconditional Jump				
Short	11101011 8-bit displacement	7 + m		j
Direct within Segment	11101001 full displacement	7 + m		j
Register/Memory Indirect within Segment	11111111 mod100 r/m	9 + m/14 + m	2/4	a,j
Direct Intersegment	11101010 unsigned full offset, selector	37 + m	5	c,d,j
Via Call Gate to Same Privilege Level		53 + m	9	a,c,d,j
From 386 Task to 386 TSS		395	124	a,c,d,j
Indirect Intersegment	11111111 mod101 r/m	37 + m	9	a,c,d,j
Via Call Gate to Same Privilege Level		59 + m	13	a,c,d,j
From 386 Task to 386 TSS		401	124	a,c,d,j

9

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format			Clock Counts	Number of Data Cycles	Notes
CONTROL TRANSFER (Continued)						
RET = Return from CALL:						
Within Segment	11000011			12 + m	2	a,j,p
Within Segment Adding Immediate to SP	11000010	16-bit displ		12 + m	2	a,j,p
Intersegment	11001011			36 + m	4	a,c,d,j,p
Intersegment Adding Immediate to SP	11001010	16-bit displ		36 + m	4	a,c,d,j,p
to Different Privilege Level						
Intersegment				80	4	c,d,j,p
Intersegment Adding Immediate to SP				80	4	c,d,j,p
CONDITIONAL JUMPS						
NOTE: Times Are Jump "Taken or Not Taken"						
JO = Jump on Overflow						
8-Bit Displacement	01110000	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000000	full displacement	7 + m or 3		j
JNO = Jump on Not Overflow						
8-Bit Displacement	01110001	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000001	full displacement	7 + m or 3		j
JB/JNAE = Jump on Below/Not Above or Equal						
8-Bit Displacement	01110010	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000010	full displacement	7 + m or 3		j
JNB/JAE = Jump on Not Below/Above or Equal						
8-Bit Displacement	01110011	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000011	full displacement	7 + m or 3		j
JE/JZ = Jump on Equal/Zero						
8-Bit Displacement	01110100	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000100	full displacement	7 + m or 3		j
JNE/JNZ = Jump on Not Equal/Not Zero						
8-Bit Displacement	01110101	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000101	full displacement	7 + m or 3		j
JBE/JNA = Jump on Below or Equal/Not Above						
8-Bit Displacement	01110110	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000110	full displacement	7 + m or 3		j
JNBE/JA = Jump on Not Below or Equal/Above						
8-Bit Displacement	01110111	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10000111	full displacement	7 + m or 3		j
JS = Jump on Sign						
8-Bit Displacement	01111000	8-bit displ		7 + m or 3		j
Full Displacement	00001111	10001000	full displacement	7 + m or 3		j

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format				Clock Counts	Number of Data Cycles	Notes
CONDITIONAL JUMPS (Continued)							
JNS = Jump on Not Sign							
8-Bit Displacement	01111001	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001001	full displacement		7 + m or 3		j
JP/JPE = Jump on Parity/Parity Even							
8-Bit Displacement	01111010	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001010	full displacement		7 + m or 3		j
JNP/JPO = Jump on Not Parity/Parity Odd							
8-Bit Displacement	01111011	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001011	full displacement		7 + m or 3		j
JL/JNGE = Jump on Less/Not Greater or Equal							
8-Bit Displacement	01111100	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001100	full displacement		7 + m or 3		j
JNL/JGE = Jump on Not Less/Greater or Equal							
8-Bit Displacement	01111101	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001101	full displacement		7 + m or 3		j
JLE/JNG = Jump on Less or Equal/Not Greater							
8-Bit Displacement	01111110	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001110	full displacement		7 + m or 3		j
JNLE/JG = Jump on Not Less or Equal/Greater							
8-Bit Displacement	01111111	8-bit displ			7 + m or 3		j
Full Displacement	00001111	10001111	full displacement		7 + m or 3		j
JECXZ = Jump on ECX Zero	11100011	8-bit displ			9 + m or 5		j
(Address Size Prefix Differentiates JCXZ from JECXZ)							
LOOP = Loop ECX Times	11100010	8-bit displ			11 + m		j
LOOPZ/LOOPE = Loop with Zero/Equal	11100001	8-bit displ			11 + m		j
LOOPNZ/LOOPNE = Loop While Not Zero	11100000	8-bit displ			11 + m		j
CONDITIONAL BYTE SET **NOTE:** Times Are Register/Memory							
SETO = Set Byte on Overflow							
To Register/Memory	00001111	10010000	mod 000 r/m		4/5*	0/1*	a
SETNO = Set Byte on Not Overflow							
To Register/Memory	00001111	10010001	mod 000 r/m		4/5*	0/1*	a
SETB/SETNAE = Set Byte on Below/Not Above or Equal							
To Register/Memory	00001111	10010010	mod 000 r/m		4/5*	0/1*	a

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format			Clock Counts	Number of Data Cycles	Notes
CONDITIONAL BYTE SET (Continued)						
SETNB = Set Byte on Not Below/Above or Equal						
To Register/Memory	00001111	10010011	mod000 r/m	4/5*	0/1*	a
SETE/SETZ = Set Byte on Equal/Zero						
To Register/Memory	00001111	10010100	mod000 r/m	4/5*	0/1*	a
SETNE/SETNZ = Set Byte on Not Equal/Not Zero						
To Register/Memory	00001111	10010101	mod000 r/m	4/5*	0/1*	a
SETBE/SETNA = Set Byte on Below or Equal/Not Above						
To Register/Memory	00001111	10010110	mod000 r/m	4/5*	0/1*	a
SETNBE/SETA = Set Byte on Not Below or Equal/Above						
To Register/Memory	00001111	10010111	mod000 r/m	4/5*	0/1*	a
SETS = Set Byte on Sign						
To Register/Memory	00001111	10011000	mod000 r/m	4/5*	0/1*	a
SETNS = Set Byte on Not Sign						
To Register/Memory	00001111	10011001	mod000 r/m	4/5*	0/1*	a
SETP/SETPE = Set Byte on Parity/Parity Even						
To Register/Memory	00001111	10011010	mod000 r/m	4/5*	0/1*	a
SETNP/SETPO = Set Byte on Not Parity/Parity Odd						
To Register/Memory	00001111	10011011	mod000 r/m	4/5*	0/1*	a
SETL/SETNGE = Set Byte on Less/Not Greater or Equal						
To Register/Memory	00001111	10011100	mod000 r/m	4/5*	0/1*	a
SETNL/SETGE = Set Byte on Not Less/Greater or Equal						
To Register/Memory	00001111	01111101	mod000 r/m	4/5*	0/1*	a
SETLE/SETNG = Set Byte on Less or Equal/Not Greater						
To Register/Memory	00001111	10011110	mod000 r/m	4/5*	0/1*	a
SETNLE/SETG = Set Byte on Not Less or Equal/Greater						
To Register/Memory	00001111	10011111	mod000 r/m	4/5*	0/1*	a
ENTER = Enter Procedure	11001000	16-bit displacement, 8-bit level				
L = 0				10		a
L = 1				14	1	a
L > 1				17 + 8(n − 1)	4(n − 1)	a
LEAVE = Leave Procedure	11001001			6		a

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
INTERRUPT INSTRUCTIONS				
INT = Interrupt:				
Type Specified	11001101 | type			
Via Interrupt or Trap Gate to Same Privilege Level		71	14	c,d,j,p
Via Interrupt or Trap Gate to Different Privilege Level		111	14	c,d,j,p
From 386 Task to 386 TSS via Task Gate		467	140	c,d,j,p
Type 3	11001100			
Via Interrupt or Trap Gate to Same Privilege Level		71	14	c,d,j,p
Via Interrupt or Trap Gate to Different Privilege Level		111	14	c,d,j,p
From 386 Task to 386 TSS via Task Gate		308	138	c,d,j,p
INTO = Interrupt 4 if Overflow Flag Set	11001110			
If OF = 1:		3		
If OF = 0				
Via Interrupt or Trap Gate to Same Privilege Level		71	14	c,d,j,p
Via Interrupt or Trap Gate to Different Privilege Level		111	14	c,d,j,p
From 386 Task to 386 TSS via Task Gate		413	138	c,d,j,p

9

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number Of Data Cycles	Notes
INTERRUPT INSTRUCTIONS (Continued)				
Bound = Out of Range Interrupt 5 If Detect Value	01100010 | mod reg r/m			
If In Range		10	0	a,c,d,j,o,p
If Out of Range:				
Via Interrupt or Trap Gate to Same Privilege Level		71	14	c,d,j,p
Via Interrupt or Trap Gate to Different Privilege Level		111	14	c,d,j,p
From 386 Task to 386 TSS via Task Gate		398	138	c,d,j,p
INTERRUPT RETURN				
IRET = Interrupt Return	11001111			
To the Same Privilege Level (within Task)		42	5	a,c,d,j,p
To Different Privilege Level (within Task)		86	5	a,c,d,j,p
From 386 Task to 386 TSS		328	138	c,d,j,p
PROCESSOR CONTROL				
HLT = HALT	11110100	5		b
MOV = Move to and from Control/Debug/Test Registers				
CR0 from register	00001111 | 00100010 | 11 eee reg	10		b
Register from CR0	00001111 | 00100000 | 11 eee reg	6		b
DR0–3 from Register	00001111 | 00100011 | 11 eee reg	22		b
DR6–7 from Register	00001111 | 00100011 | 11 eee reg	16		b
Register from DR6–7	00001111 | 00100001 | 11 eee reg	14		b
Register from DR0–3	00001111 | 00100001 | 11 eee reg	22		b
NOP = No Operation	10010000	3		
WAIT = Wait until $\overline{\text{BUSY}}$ Pin is Negated	10011011	6		

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
PROCESSOR EXTENSION INSTRUCTIONS				
Processor Extension Escape	11011TTT | mod LLL r/m TTT and LLL bits are opcode information for coprocessor.	See 80387SX Data Sheet		a
PREFIX BYTES				
Address Size Prefix	01100111	0		
LOCK = Bus Lock Prefix	11110000	0		f
Operand Size Prefix	01100110	0		
Segment Override Prefix				
CS:	00101110	0		
DS:	00111110	0		
ES:	00100110	0		
FS:	01100100	0		
GS:	01100101	0		
SS:	00110110	0		
PROTECTION CONTROL				
ARPL = Adjust Requested Privilege Level				
From Register/Memory	01100011 | mod reg r/m	20/21**	2**	a
LAR = Load Access Rights				
From Register/Memory	00001111 | 00000010 | mod reg r/m	17/18*	1*	a,c,i,p
LGDT = Load Global Descriptor				
Table Register	00001111 | 00000001 | mod 010 r/m	13**	3*	a,e
LIDT = Load Interrupt Descriptor				
Table Register	00001111 | 00000001 | mod 011 r/m	13**	3*	a,e
LLDT = Load Local Descriptor				
Table Register to Register/Memory	00001111 | 00000000 | mod 010 r/m	24/28*	5*	a,c,e,p
LMSW = Load Machine Status Word				
From Register/Memory	00001111 | 00000001 | mod 110 r/m	10/13*	1*	a,e
LSL = Load Segment Limit				
From Register/Memory	00001111 | 00000011 | mod reg r/m			
Byte-Granular Limit		24/27*	2*	a,c,i,p
Page-Granular Limit		29/32*	2*	a,c,i,p
LTR = Load Task Register				
From Register/Memory	00001111 | 00000000 | mod 001 r/m	27/31*	4*	a,c,e,p
SGDT = Store Global Descriptor				
Table Register	00001111 | 00000001 | mod 000 r/m	11*	3*	a
SIDT = Store Interrupt Descriptor				
Table Register	00001111 | 00000001 | mod 001 r/m	11*	3*	a
SLDT = Store Local Descriptor Table Register				
To Register/Memory	00001111 | 00000000 | mod 000 r/m	2/2*	4*	a

9

Table 8.1. 80376 Instruction Set Clock Count Summary (Continued)

Instruction	Format	Clock Counts	Number of Data Cycles	Notes
PROTECTION CONTROL (Continued)				
SMSW = Store Machine Status Word	00001111 | 00000001 | mod100 r/m	2/2*	1*	a, c
STR = Store Task Register To Register/Memory	00001111 | 00000000 | mod001 r/m	2/2*	1*	a
VERR = Verify Read Accesss Register/Memory	00001111 | 00000000 | mod100 r/m	10/11**	2**	a,c,i,p
VERW = Verify Write Accesss	00001111 | 00000000 | mod101 r/m	15/16**	2**	a,c,i,p

NOTES:

a. Exception 13 fault (general violation) will occur if the memory operand in CS, DS, ES, FS or GS cannot be used due to either a segment limit violation or access rights violation. If a stack limit is violated, and exception 12 (stack segment limit violation or not present) occurs.

b. For segment load operations, the CPL, RPL and DPL must agree with the privilege rules to avoid an exception 13 fault (general protection violation). The segments's descriptor must indicate "present" or exception 11 (CS, DS, ES, FS, GS not present). If the SS register is loaded and a stack segment not present is detected, an exception 12 (stack segment limit violation or not present occurs).

c. All segment descriptor accesses in the GDT or LDT made by this instruction will automatically assert $\overline{\text{LOCK}}$ to maintain descriptor integrity in multiprocessor systems.

d. JMP, CALL, INT, RET and IRET instructions referring to another code segment will cause an exception 13 (general protection violation) if an applicable privilege rule is volated.

e. An exception 13 fault occurs if CPL is greater than 0.

f. An exception 13 fault occurs if CPL is greater than IOPL.

g. The IF bit of the flag register is not updated if CPL is greater than IOPL. The IOPL field of the flag register is updated only if CPL = 0.

h. Any violation of privelege rules as applied to the selector operand does not cause a protection exception; rather, the zero flag is cleared.

i. If the coprocessor's memory operand violates a segment limit or segment access rights, an exception 13 fault (general protection exception) will occur before the ESC instruction is executed. An exception 12 fault (stack segment limit violation or no present) will occur if the stack limit is violated by the operand's starting address.

j. The destination of a JMP, CALL, INT, RET or IRET must be in the defined limit of a code segment or an exception 13 fault (general protection violation) will occur.

k. If CPL $\leq$ IOPL

l. If CPL > IOPL

m. $\overline{\text{LOCK}}$ is automatically asserted, regardless of the presence or absence of the $\overline{\text{LOCK}}$ prefix.

n. The 80376 uses an early-out multiply algorithm. The actual number of clocks depends on the position of the most significant bit in the operand (multiplier). Clock counts given are minimum to maximum. To calculate actual clocks use the following formula:

Actual Clock = if m < > 0 then max ([$\log_2$ |m|], 3) + 9 clocks:
if m = 0 then 12 clocks (where m is the multiplier)

o. An exception may occur, depending on the value of the operand.

p. $\overline{\text{LOCK}}$ is asserted during descriptor table accesses.

8.2 INSTRUCTION ENCODING

Overview

All instruction encodings are subsets of the general instruction format shown in Figure 8.1. Instructions consist of one or two primary opcode bytes, possibly an address specifier consisting of the "mod r/m" byte and "scaled index" byte, a displacement if required, and an immediate data field if required.

Within the primary opcode or opcodes, smaller encoding fields may be defined. These fields vary according to the class of operation. The fields define such information as direction of the operation, size of the displacements, register encoding, or sign extension.

Almost all instructions referring to an operand in memory have an addressing mode byte following the primary opcode byte(s). This byte, the mod r/m byte, specifies the address mode to be used. Certain encodings of the mod r/m byte indicate a second addressing byte, the scale-index-base byte, follows the mod r/m byte to fully specify the addressing mode.

Addressing modes can include a displacement immediately following the mod r/m byte, or scaled index byte. If a displacement is present, the possible sizes are 8, 16 or 32 bits.

If the instruction specifies an immediate operand, the immediate operand follows any displacement bytes. The immediate operand, if specified, is always the last field of the instruction.

Figure 8.1 illustrates several of the fields that can appear in an instruction, such as the mod field and the r/m field, but the Figure does not show all fields. Several smaller fields also appear in certain instructions, sometimes within the opcode bytes themselves. Table 8.2 is a complete list of all fields appearing in the 80376 instruction set. Further ahead, following Table 8.2, are detailed tables for each field.

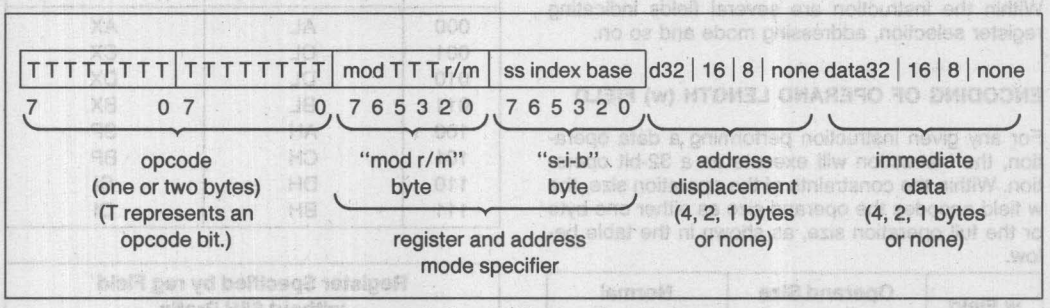


Figure 8.1. General Instruction Format

Table 8.2. Fields within 80376 Instructions

Field Name	Description	Number of Bits
w	Specifies if Data is Byte or Full Size (Full Size is either 16 or 32 Bits	1
d	Specifies Direction of Data Operation	1
s	Specifies if an Immediate Data Field Must be Sign-Extended	1
reg	General Register Specifier	3
mod r/m	Address Mode Specifier (Effective Address can be a General Register)	2 for mod; 3 for r/m
ss	Scale Factor for Scaled Index Address Mode	2
index	General Register to be used as Index Register	3
base	General Register to be used as Base Register	3
sreg2	Segment Register Specifier for CS, SS, DS, ES	2
sreg3	Segment Register Specifier for CS, SS, DS, ES, FS, GS	3
tttn	For Conditional Instructions, Specifies a Condition Asserted or a Condition Negated	4

Note: Table 8.1 shows encoding of individual instructions.

16-Bit Extensions of the Instruction Set

Two prefixes, the operand size prefix (66H) and the effective address size prefix (67H), allow overriding individually the default selection of operand size and effective address size. These prefixes may precede any opcode bytes and affect only the instruction they precede. If necessary, one or both of the prefixes may be placed before the opcode bytes. The presence of the operand size prefix (66H) and the effective address prefix will allow 16-bit data operation and 16-bit effective address calculations.

For instructions with more than one prefix, the order of prefixes is unimportant.

Unless specified otherwise, instructions with 8-bit and 16-bit operands do not affect the contents of the high-order bits of the extended registers.

Encoding of Instruction Fields

Within the instruction are several fields indicating register selection, addressing mode and so on.

ENCODING OF OPERAND LENGTH (w) FIELD

For any given instruction performing a data operation, the instruction will execute as a 32-bit operation. Within the constraints of the operation size, the w field encodes the operand size as either one byte or the full operation size, as shown in the table below.

w Field	Operand Size with 66H Prefix	Normal Operand Size
0	8 Bits	8 Bits
1	16 Bits	32 Bits

ENCODING OF THE GENERAL REGISTER (reg) FIELD

The general register is specified by the reg field, which may appear in the primary opcode bytes, or as the reg field of the "mod r/m" byte, or as the r/m field of the "mod r/m" byte.

Encoding of reg Field When w Field is not Present in Instruction

reg Field	Register Selected with 66H Prefix	Register Selected During 32-Bit Data Operations
000	AX	EAX
001	CX	ECX
010	DX	EDX
011	BX	EBX
100	SP	ESP
101	BP	EBP
110	SI	ESI
111	DI	EDI

Encoding of reg Field When w Field is Present in Instruction

Register Specified by reg Field with 66H Prefix		
reg	Function of w Field	
	(when w = 0)	(when w = 1)
000	AL	AX
001	CL	CX
010	DL	DX
011	BL	BX
100	AH	SP
101	CH	BP
110	DH	SI
111	BH	DI

Register Specified by reg Field without 66H Prefix		
reg	Function of w Field	
	(when w = 0)	(when w = 1)
000	AL	EAX
001	CL	ECX
010	DL	EDX
011	BL	EBX
100	AH	ESP
101	CH	EBP
110	DH	ESI
111	BH	EDI

ENCODING OF THE SEGMENT REGISTER (sreg) FIELD

The sreg field in certain instructions is a 2-bit field allowing one of the CS, DS, ES or SS segment registers to be specified. The sreg field in other instructions is a 3-bit field, allowing the FS and GS segment registers to be specified also.

2-Bit sreg2 Field

2-Bit sreg2 Field	Segment Register Selected
00	ES
01	CS
10	SS
11	DS

3-Bit sreg3 Field

3-Bit sreg3 Field	Segment Register Selected
000	ES
001	CS
010	SS
011	DS
100	FS
101	GS
110	do not use
111	do not use

ENCODING OF ADDRESS MODE

Except for special instructions, such as PUSH or POP, where the addressing mode is pre-determined, the addressing mode for the current instruction is specified by addressing bytes following the primary opcode. The primary addressing byte is the "mod r/m" byte, and a second byte of addressing information, the "s-i-b" (scale-index-base) byte, can be specified.

The s-i-b byte (scale-index-base byte) is specified when using 32-bit addressing mode and the "mod r/m" byte has r/m = 100 and mod = 00, 01 or 10. When the sib byte is present, the 32-bit addressing mode is a function of the mod, ss, index, and base fields.

The primary addressing byte, the "mod r/m" byte, also contains three bits (shown as TTT in Figure 8.1) sometimes used as an extension of the primary opcode. The three bits, however, may also be used as a register field (reg).

When calculating an effective address, either 16-bit addressing or 32-bit addressing is used. 16-bit addressing uses 16-bit address components to calculate the effective address while 32-bit addressing uses 32-bit address components to calculate the effective address. When 16-bit addressing is used, the "mod r/m" byte is interpreted as a 16-bit addressing mode specifier. When 32-bit addressing is used, the "mod r/m" byte is interpreted as a 32-bit addressing mode specifier.

Tables on the following three pages define all encodings of all 16-bit addressing modes and 32-bit addressing modes.

9

Encoding of Normal Address Mode with "mod r/m" byte (no "s-i-b" byte present):

mod r/m	Effective Address
00 000	DS:[EAX]
00 001	DS:[ECX]
00 010	DS:[EDX]
00 011	DS:[EBX]
00 100	s-i-b is present
00 101	DS:d32
00 110	DS:[ESI]
00 111	DS:[EDI]
01 000	DS:[EAX + d8]
01 001	DS:[ECX + d8]
01 010	DS:[EDX + d8]
01 011	DS:[EBX + d8]
01 100	s-i-b is present
01 101	SS:[EBP + d8]
01 110	DS:[ESI + d8]
01 111	DS:[EDI + d8]

mod r/m	Effective Address
10 000	DS:[EAX + d32]
10 001	DS:[ECX + d32]
10 010	DS:[EDX + d32]
10 011	DS:[EBX + d32]
10 100	s-i-b is present
10 101	SS:[EBP + d32]
10 110	DS:[ESI + d32]
10 111	DS:[EDI + d32]
11 000	register—see below
11 001	register—see below
11 010	register—see below
11 011	register—see below
11 100	register—see below
11 101	register—see below
11 110	register—see below
11 111	register—see below

Register Specified by reg or r/m during Normal Data Operations:		
mod r/m	function of w field	
	(when w = 0)	(when w = 1)
11 000	AL	EAX
11 001	CL	ECX
11 010	DL	EDX
11 011	BL	EBX
11 100	AH	ESP
11 101	CH	EBP
11 110	DH	ESI
11 111	BH	EDI

Register Specified by reg or r/m during 16-Bit Data Operations: (66H Prefix)		
mod r/m	function of w field	
	(when w = 0)	(when w = 1)
11 000	AL	AX
11 001	CL	CX
11 010	DL	DX
11 011	BL	BX
11 100	AH	SP
11 101	CH	BP
11 110	DH	SI
11 111	BH	DI

Encoding of 16-bit Address Mode with "mod r/m" Byte Using 67H Prefix

mod r/m	Effective Address
00 000	DS:[BX + SI]
00 001	DS:[BX + DI]
00 010	SS:[BP + SI]
00 011	SS:[BP + DI]
00 100	DS:[SI]
00 101	DS:[DI]
00 110	DS:d16
00 111	DS:[BX]
01 000	DS:[BX + SI + d8]
01 001	DS:[BX + DI + d8]
01 010	SS:[BP + SI + d8]
01 011	SS:[BP + DI + d8]
01 100	DS:[SI + d8]
01 101	DS:[DI + d8]
01 110	SS:[BP + d8]
01 111	DS:[BX + d8]

mod r/m	Effective Address
10 000	DS:[BX + SI + d16]
10 001	DS:[BX + DI + d16]
10 010	SS:[BP + SI + d16]
10 011	SS:[BP + DI + d16]
10 100	DS:[SI + d16]
10 101	DS:[DI + d16]
10 110	SS:[BP + d16]
10 111	DS:[BX + d16]
11 000	register—see below
11 001	register—see below
11 010	register—see below
11 011	register—see below
11 100	register—see below
11 101	register—see below
11 110	register—see below
11 111	register—see below

9

Encoding of 32-bit Address Mode ("mod r/m" byte and "s-i-b" byte present):

mod base	Effective Address
00 000	DS:[EAX + (scaled index)]
00 001	DS:[ECX + (scaled index)]
00 010	DS:[EDX + (scaled index)]
00 011	DS:[EBX + (scaled index)]
00 100	SS:[ESP + (scaled index)]
00 101	DS:[d32 + (scaled index)]
00 110	DS:[ESI + (scaled index)]
00 111	DS:[EDI + (scaled index)]
01 000	DS:[EAX + (scaled index) + d8]
01 001	DS:[ECX + (scaled index) + d8]
01 010	DS:[EDX + (scaled index) + d8]
01 011	DS:[EBX + (scaled index) + d8]
01 100	SS:[ESP + (scaled index) + d8]
01 101	SS:[EBP + (scaled index) + d8]
01 110	DS:[ESI + (scaled index) + d8]
01 111	DS:[EDI + (scaled index) + d8]
10 000	DS:[EAX + (scaled index) + d32]
10 001	DS:[ECX + (scaled index) + d32]
10 010	DS:[EDX + (scaled index) + d32]
10 011	DS:[EBX + (scaled index) + d32]
10 100	SS:[ESP + (scaled index) + d32]
10 101	SS:[EBP + (scaled index) + d32]
10 110	DS:[ESI + (scaled index) + d32]
10 111	DS:[EDI + (scaled index) + d32]

NOTE:
Mod field in "mod r/m" byte; ss, index, base fields in "s-i-b" byte.

ss	Scale Factor
00	x1
01	x2
10	x4
11	x8

index	Index Register
000	EAX
001	ECX
010	EDX
011	EBX
100	no index reg**
101	EBP
110	ESI
111	EDI

****IMPORTANT NOTE:**
When index field is 100, indicating "no index register," then ss field MUST equal 00. If index is 100 and ss does not equal 00, the effective address is undefined.

ENCODING OF OPERATION DIRECTION (d) FIELD

In many two-operand instructions the d field is present to indicate which operand is considered the source and which is the destination.

d	Direction of Operation
0	Register/Memory <- - Register "reg" Field Indicates Source Operand; "mod r/m" or "mod ss index base" Indicates Destination Operand
1	Register <- - Register/Memory "reg" Field Indicates Destination Operand; "mod r/m" or "mod ss index base" Indicates Source Operand

ENCODING OF SIGN-EXTEND (s) FIELD

The s field occurs primarily to instructions with immediate data fields. The s field has an effect only if the size of the immediate data is 8 bits and is being placed in a 16-bit or 32-bit destination.

s	Effect on Immediate Data8	Effect on Immediate Data 16|32
0	None	None
1	Sign-Extend Data8 to Fill 16-Bit or 32-Bit Destination	None

ENCODING OF CONDITIONAL TEST (tttn) FIELD

For the conditional instructions (conditional jumps and set on condition), tttn is encoded with n indicating to use the condition (n = 0) or its negation (n = 1), and ttt giving the condition to test.

Mnemonic	Condition	tttn
O	Overflow	0000
NO	No Overflow	0001
B/NAE	Below/Not Above or Equal	0010
NB/AE	Not Below/Above or Equal	0011
E/Z	Equal/Zero	0100
NE/NZ	Not Equal/Not Zero	0101
BE/NA	Below or Equal/Not Above	0110
NBE/A	Not Below or Equal/Above	0111
S	Sign	1000
NS	Not Sign	1001
P/PE	Parity/Parity Even	1010
NP/PO	Not Parity/Parity Odd	1011
L/NGE	Less Than/Not Greater or Equal	1100
NL/GE	Not Less Than/Greater or Equal	1101
LE/NG	Less Than or Equal/Greater Than	1110
NLE/G	Not Less or Equal/Greater Than	1111

ENCODING OF CONTROL OR DEBUG REGISTER (eee) FIELD

For the loading and storing of the Control and Debug registers.

When Interpreted as Control Register Field

eee Code	Reg Name
000	CR0
010	Reserved
011	Reserved
Do not use any other encoding	

When Interpreted as Debug Register Field

eee Code	Reg Name
000	DR0
001	DR1
010	DR2
011	DR3
110	DR6
111	DR7
Do not use any other encoding	

9

9.0 REVISION HISTORY

The sections significantly revised since version -003 are:

Section 1.0	Added $\overline{FLT}$ pin.
Section 4.4	Added description of FLOAT operation and ONCE Mode. Figure 4.20 is new.
Section 4.6	Added revision identifier information for change to CHMOS IV manufacturing process.
Section 5.0	Both packages now specified for 0°C–115°C case temperature operation. Thermal resistance values changed.
Section 6.3	I_{CC} Max. specifications changed from 400 mA (cold) and 360 mA (hot) to 275 mA (cold, 16 MHz) and 305 mA (cold, 20 MHz).
Section 6.4	HLDA Valid Delay, t_{14}, min. changed from 6 ns to 4 ns. Added 20 MHz A.C. specifications in Table 6.5. Replaced Capacitive Derating Curves in Figures 6.8–6.10 to reflect new manufacturing process. Replaced I_{CC} vs. Frequency data (Figure 6.11) to reflect new specifications.

The sections significantly revised since version -002 are:

Section 1.0	Modified table 1.1. to list pins in alphabetical order.

The sections significantly revised since version -001 are:

Section 2.0	Figure 2.0 was updated to show the 16-bit registers SI, DI, BP and SP.
Section 2.1	Figure 2.2 was updated to show the correct bit polarity for bit 4 in the CR0 register.
Section 2.1	Tables 2.1 and 2.2 were updated to include additional information on the EFLAGs and CR0 registers.
Section 2.3	Figure 2.3 was updated to more accurately reflect the addressing mechanism of the 80376.
Section 2.6	In the subsection **Maskable Interrupt** a paragraph was added to describe the effect of interrupt gates on the IF EFLAGs bit.
Section 2.8	Table 2.7 was updated to reflect the correct power up condition of the CR0 register.
Section 2.10	Figure 2.6 was updated to show the correct bit positions of the BT, BS and BD bits in the DR6 register.
Section 3.0	Figure 3.1 was updated to clearly show the address calculation process.
Section 3.2	The subsection **DESCRIPTORS** was elaborated upon to clearly define the relationship between the linear address space and physical address space of the 80376.
Section 3.2	Figures 3.3 and 3.4 were updated to show the AVL bit field.
Section 3.3	The last sentence in the first paragraph of subsection **PROTECTION AND I/O PERMISSION BIT MAP** was deleted. This was an incorrect statement.
Section 4.1	In the Subsection **ADDRESS BUS ($\overline{BHE}$, $\overline{BLE}$, A_{23}–A_1** last sentence in the first paragraph was updated to reflect the numerics operand addresses as 8000FCH and 8000FEH. Because the 80376 sometimes does a double word I/O access a second access to 8000FEH can be seen.
Section 4.1	The Subsection **Hold Lantencies** was updated to describe how 32-bit and unaligned accesses are internally locked but do not assert the $\overline{LOCK}$ signal.
Section 4.2	Table 4.6 was updated to show the correct active data bits during a $\overline{BLE}$ assertion.

9.0 REVISION HISTORY (Continued)

Section 4.4 This section was updated to correctly reflect the pipelining of the address and status of the 80376 as opposed to "Address Pipelining" which occurs on processors such as the 80286.

Section 4.6 Table 4.7 was updated to show the correct Revision number, 05H.

Section 4.7 Table 4.8 was updated to show the numerics operand register 8000FEH. This address is seen when the 80376 does a DWORD operation to the port address 8000FCH.

Section 5.0 In the first paragraph the case temperatures were updated to reflect the 0°C–115°C for the ceramic package and 0°C–110°C for the plastic package.

Section 6.2 Table 6.2 was updated to reflect the Case Temperature under Bias specification of −65°C–120°C.

Section 6.4 Figure 6.8 vertical axis was updated to reflect "Output Valid Delay (ns)".

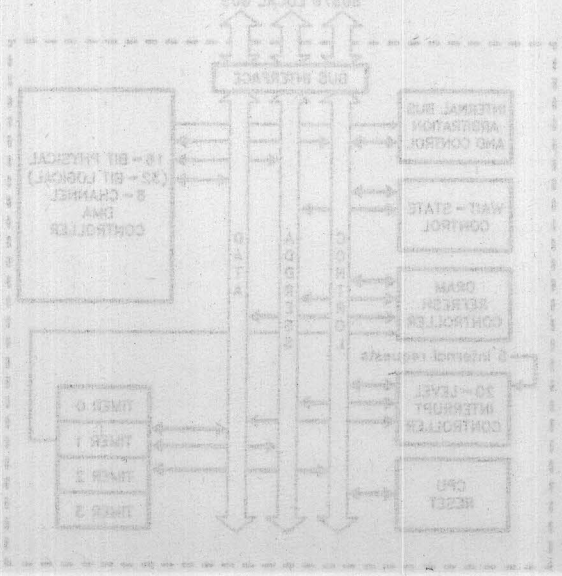
Section 6.4 Figure 6.11 was updated to show typical I_{CC} vs Frequency for the 80376.

Section 8.1 The clock counts and opcodes for various instructions were updated to their correct values.

Section 8.2 The section **INSTRUCTION ENCODING** was appended to the data sheet.

The sections significantly revised since version -002 are:

Section 1.0 Modified table 1.1. to list pins in alphabetical order.

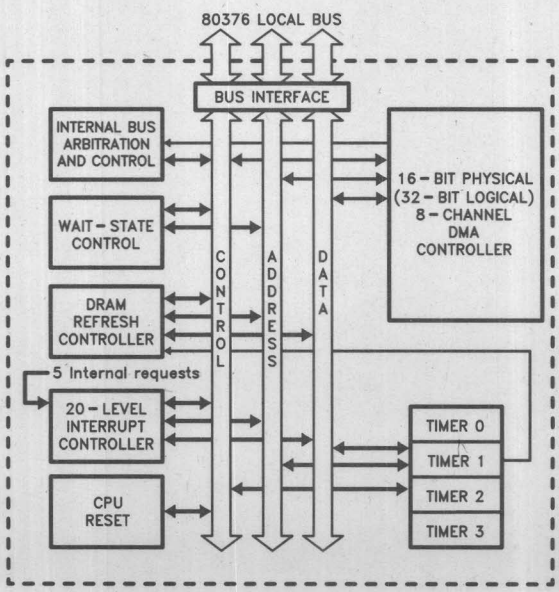


82370
INTEGRATED SYSTEM PERIPHERAL

- **High Performance 32-Bit DMA Controller for 16-Bit Bus**
  - **16 MBytes/Sec Maximum Data Transfer Rate at 16 MHz**
  - **8 Independently Programmable Channels**
- **20-Source Interrupt Controller**
  - **Individually Programmable Interrupt Vectors**
  - **15 External, 5 Internal Interrupts**
  - **82C59A Superset**
- **Four 16-Bit Programmable Interval Timers**
  - **82C54 Compatible**
- **Software Compatible to 82380**
- **Programmable Wait State Generator**
  - **0 to 15 Wait States Pipelined**
  - **1 to 16 Wait States Non-Pipelined**
- **DRAM Refresh Controller**
- **80376 Shutdown Detect and Reset Control**
  - **Software/Hardware Reset**
- **High Speed CHMOS III Technology**
- **100-Pin Plastic Quad Flat-Pack Package and 132-Pin Pin Grid Array Package**
  (See Packaging Handbook Order #231369)
- **Optimized for Use with the 80376 Microprocessor**
  - **Resides on Local Bus for Maximum Bus Bandwidth**

The 82370 is a multi-function support peripheral that integrates system functions necessary in an 80376 environment. It has eight channels of high performance 32-bit DMA (32-bit internal, 16-bit external) with the most efficient transfer rates possible on the 80376 bus. System support peripherals integrated into the 82370 provide Interrupt Control, Timers, Wait State generation, DRAM Refresh Control, and System Reset logic.

The 82370's DMA Controller can transfer data between devices of different data path widths using a single channel. Each DMA channel operates independently in any of several modes. Each channel has a temporary data storage register for handling non-aligned data without the need for external alignment logic.



290164-1

Internal Block Diagram

September 1990
Order Number: 290164-004

Table of Contents

CONTENTS

PAGE

Pin Descriptions 9-102

1.0 Functional Overview 9-107

1.1 82370 Architecture 9-107

1.1.1 DMA (Direct Memory Access) Controller 9-109

1.1.2 Programmable Interval Timers 9-110

1.1.3 Interrupt Controller 9-111

1.1.4 Wait State Generator 9-112

1.1.5 DRAM (Dynamic RAM) Refresh Controller 9-112

1.1.6 CPU Reset Function 9-112

1.1.7 Register Map Relocation 9-113

1.2 Host Interface 9-113

2.0 80376 Host Interface 9-113

2.1 Master and Slave Modes 9-114

2.2 80376 Interface Signals 9-114

2.2.1 Clock (CLK2) 9-115

2.2.2 Data Bus (D_0–D_{15}) 9-115

2.2.3 Address Bus (A_{23}–A_1) 9-115

2.2.4 Byte Enable (BHE#, BLE#) 9-115

2.2.5 Bus Cycle Definition Signals (D/C#, W/R#, M/IO#) 9-116

2.2.6 Address Status (ADS#) 9-116

2.2.7 Transfer Acknowledge (READY#) 9-116

2.2.8 Next Address Request (NA#) 9-116

2.2.9 Reset (RESET, CPURST) 9-117

2.2.10 Interrupt Out (INT) 9-118

2.3 82370 Bus Timing 9-118

2.3.1 Address Pipelining 9-118

2.3.2 Master Mode Bus Timing 9-118

2.3.3 Slave Mode Bus Timing 9-119

3.0 DMA Controller 9-121

3.1 Functional Description 9-121

3.2 Interface Signals 9-123

3.2.1 DREQn and EDACK (0–2) 9-124

3.2.2 HOLD and HLDA 9-124

3.2.3 EOP# 9-125

3.3 Modes of Operation 9-125

3.3.1 Target/Requester Definition 9-125

3.3.2 Buffer Transfer Processes 9-126

9

CONTENTS

PAGE

3.0 DMA Controller (Continued)
3.3.3 Data Transfer Modes ... 9-126
3.3.4 Channel Priority Arbitration ... 9-130
3.3.5 Combining Priority Modes ... 9-132
3.3.6 Bus Operation ... 9-132
3.3.6.1 Fly-By Transfers ... 9-132
3.3.6.2 Two-Cycle Transfers ... 9-133
3.3.6.3 Data Path Width and Data Transfer Rate Considerations ... 9-133
3.3.6.4 Read, Write, and Verify Cycles ... 9-134
3.4 Bus Arbitration and Handshaking ... 9-134
3.4.1 Synchronous and Asynchronous Sampling of DREQn and EOP# ... 9-136
3.4.2 Arbitration of Cascaded Master Requests ... 9-138
3.4.3 Arbitration of Refresh Requests ... 9-139
3.5 DMA Controller Register Overview ... 9-140
3.5.1 Control/Status Registers ... 9-140
3.5.2 Channel Registers ... 9-141
3.5.3 Temporary Registers ... 9-142
3.6 DMA Controller Programming ... 9-142
3.6.1 Buffer Processes ... 9-143
3.6.1.1 Single Buffer Process ... 9-143
3.6.1.2 Buffer Auto-Initialize Process ... 9-143
3.6.1.3 Buffer Chaining Process ... 9-144
3.6.2 Data Transfer Modes ... 9-144
3.6.3 Cascaded Bus Masters ... 9-144
3.6.4 Software Commands ... 9-144
3.7 Register Definitions ... 9-144
3.8 8237A Compatibility ... 9-151

4.0 Programmable Interrupt Controller (PIC) ... 9-151
4.1 Functional Description ... 9-151
4.1.1 Internal Block Diagram ... 9-151
4.1.2 Interrupt Controller Banks ... 9-152
4.2 Interface Signals ... 9-154
4.2.1 Interrupt Inputs ... 9-154
4.2.2 Interrupt Output (INT) ... 9-154
4.3 Bus Functional Description ... 9-154
4.4 Modes of Operation ... 9-155
4.4.1 End-of-Interrupt ... 9-156
4.4.2 Interrupt Priorities ... 9-156
4.4.2.1 Fully Nested Mode ... 9-156
4.4.2.2 Automatic Rotation—Equal Priority Devices ... 9-157
4.4.2.3 Specific Rotation—Specific Priority ... 9-158
4.4.2.4 Interrupt Priority Mode Summary ... 9-158

CONTENTS

PAGE

4.0 Programmable Interrupt Controller (Continued)
4.4.3 Interrupt Masking ... 9-158
4.4.4 Edge or Level Interrupt Triggering ... 9-159
4.4.5 Interrupt Cascading ... 9-159
4.4.5.1 Special Fully Nested Mode ... 9-160
4.4.6 Reading Interrupt Status ... 9-160
4.4.6.1 Poll Command ... 9-160
4.4.6.2 Reading Interrupt Registers ... 9-160
4.5 Register Set Overview ... 9-160
4.5.1 Initialization Command Words (ICW) ... 9-162
4.5.2 Operation Control Words (OCW) ... 9-162
4.5.3 Poll/Interrupt Request/In-Service Status Register ... 9-163
4.5.4 Interrupt Mask Register (IMR) ... 9-163
4.5.5 Vector Register (VR) ... 9-163
4.6 Programming ... 9-163
4.6.1 Initialization (ICW) ... 9-163
4.6.2 Vector Registers (VR) ... 9-164
4.6.3 Operation Control Words (OCW) ... 9-165
4.6.3.1 Read Status and Poll Commands (OCW3) ... 9-165
4.7 Register Bit Definition ... 9-165
4.8 Register Operational Summary ... 9-169

5.0 Programmable Interval Timer ... 9-169
5.1 Functional Description ... 9-169
5.1.1 Internal Architecture ... 9-170
5.2 Interface Signals ... 9-172
5.2.1 CLKIN ... 9-172
5.2.2 TOUT1, TOUT2#, TOUT3# ... 9-172
5.2.3 GATE ... 9-172
5.3 Modes of Operation ... 9-172
5.3.1 Mode 0—Interrupt on Terminal Count ... 9-172
5.3.2 Mode 1—GATE Retriggerable One-Shot ... 9-173
5.3.3 Mode 2—Rate Generator ... 9-174
5.3.4 Mode 3—Square Wave Generator ... 9-175
5.3.5 Mode 4—Initial Count Triggered Strobe ... 9-177
5.3.6 Mode 5—GATE Retriggerable Strobe ... 9-178
5.3.7 Operation Common to All Modes ... 9-179
5.3.7.1 GATE ... 9-179
5.3.7.2 Counter ... 9-180
5.4 Register Set Overview ... 9-180
5.4.1 Counter 0, 1, 2, 3 Registers ... 9-180
5.4.2 Control Word Register I & II ... 9-180

9

CONTENTS

PAGE

5.0 Programmable Interval Timer (Continued)
5.5 Programming 9-181
5.5.1 Initialization 9-181
5.5.2 Read Operation 9-181
5.6 Register Bit Definitions 9-183

6.0 Wait State Generator 9-185
6.1 Functional Description 9-185
6.2 Interface Signals 9-185
6.2.1 READY# 9-185
6.2.2 READYO# 9-185
6.2.3 WSC (0–1) 9-185
6.3 Bus Function 9-186
6.3.1 Wait States in Non-Pipelined Cycle 9-186
6.3.2 Wait States in Pipelined Cycles 9-187
6.3.3 Extending and Early Terminating Bus Cycle 9-187
6.4 Register Set Overview 9-189
6.5 Programming 9-189
6.6 Register Bit Definition 9-189
6.7 Application Issues 9-190
6.7.1 External 'READY' Control Logic 9-190

7.0 DRAM Refresh Controller 9-191
7.1 Functional Description 9-191
7.2 Interface Signals 9-191
7.2.1 TOUT1/REF# 9-191
7.3 Bus Function 9-191
7.3.1 Arbitration 9-191
7.4 Modes of Operation 9-192
7.4.1 Word Size and Refresh Address Counter 9-192
7.5 Register Set Overview 9-192
7.6 Programming 9-193
7.7 Register Bit Definition 9-193

8.0 Relocation Register, Address Decode and Chip-Select (CHPSEL#) 9-193
8.1 Relocation Register 9-193
8.1.1 I/O-Mapped 82370 9-194
8.1.2 Memory-Mapped 82370 9-194
8.2 Address Decoding 9-194
8.3 Chip-Select (CHPSEL#) 9-194

CONTENTS

PAGE

9.0 CPU Reset and Shutdown Detect 9-195
9.1 Hardware Reset 9-195
9.2 Software Reset 9-195
9.3 Shutdown Detect 9-195

10.0 Internal Control and Diagnostic Ports 9-196
10.1 Internal Control Port 9-196
10.2 Diagnostic Ports 9-196

11.0 Internal Reserved I/O Ports 9-196

12.0 Package Thermal Specifications 9-197

13.0 Electrical Specifications 9-198

Appendix A—Ports Listed by Address 9-206

Appendix B—Ports Listed by Function 9-210

Appendix C—System Notes 9-214

9

Pin Descriptions

The 82370 provides all of the signals necessary to interface an 80376 host processor. It has a separate 24-bit address and 16-bit data bus. It also has a set of control signals to support operation as a bus master or a bus slave. Several special function signals exist on the 82370 for interfacing the system support peripherals to their respective system counterparts. Following are the definitions of the individual pins of the 82370. These brief descriptions are provided as a reference. Each signal is further defined within the sections which describe the associated 82370 function.

Symbol	Type	Name and Function
A_1–A_{23}	I/O	**ADDRESS BUS:** Outputs physical memory or port I/O addresses. See **Address Bus** (2.2.3) for additional information.
BHE# BLE#	I/O	**BYTE ENABLES:** Indicate which data bytes of the data bus take part in a bus cycle. See **Byte Enable** (2.2.4) for additional information.
D_0–D_{15}	I/O	**DATA BUS:** This is the 16-bit data bus. These pins are active outputs during interrupt acknowledges, during Slave accesses, and when the 82370 is in the Master Mode.
CLK2	I	**PROCESSOR CLOCK:** This pin must be connected to the processor's clock, CLK2. The 82370 monitors the phase of this clock in order to remain synchronized with the CPU. This clock drives all of the internal synchronous circuitry.
D/C#	I/O	**DATA/CONTROL:** D/C# is used to distinguish between CPU control cycles and DMA or CPU data access cycles. It is active as an output only in the Master Mode.
W/R#	I/O	**WRITE/READ:** W/R# is used to distinguish between write and read cycles. It is active as an output only in the Master Mode.
M/IO#	I/O	**MEMORY/IO:** M/IO# is used to distinguish between memory and IO accesses. It is active as an output only in the Master Mode.
ADS#	I/O	**ADDRESS STATUS:** This signal indicates presence of a valid address on the address bus. It is active as output only in the Master Mode. ADS# is active during the first T-state where addresses and control signals are valid.
NA#	I	**NEXT ADDRESS:** Asserted by a peripheral or memory to begin a pipelined address cycle. This pin is monitored only while the 82370 is in the Master Mode. In the Slave Mode, pipelining is determined by the current and past status of the ADS# and READY# signals.
HOLD	O	**HOLD REQUEST:** This is an active-high signal to the Bus Master to request control of the system bus. When control is granted, the Bus Master activates the hold acknowledge signal (HLDA).
HLDA	I	**HOLD ACKNOWLEDGE:** This input signal tells the DMA controller that the Bus Master has relinquished control of the system bus to the DMA controller.

Pin Descriptions (Continued)

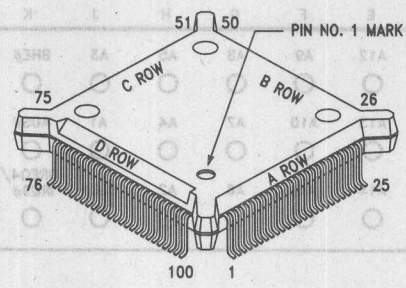
Symbol	Type	Name and Function
DREQ (0–3, 5–7)	I	**DMA REQUEST:** The DMA Request inputs monitor requests from peripherals requiring DMA service. Each of the eight DMA channels has one DREQ input. These active-high inputs are internally synchronized and prioritized. Upon request, channel 0 has the highest priority and channel 7 the lowest.
DREQ4/IRQ9#	I	**DMA/INTERRUPT REQUEST:** This is the DMA request input for channel 4. It is also connected to the interrupt controller via interrupt request 9. This internal connection is available for DMA channel 4 only. The interrupt input is active low and can be programmed as either edge or level triggered. Either function can be masked by the appropriate mask register. Priorities of the DMA channel and the interrupt request are not related but follow the rules of the individual controllers. Note that this pin has a weak internal pull-up. This causes the interrupt request to be inactive, but the DMA request will be active if there is no external connection made. Most applications will require that either one or the other of these functions be used, but not both. For this reason, it is advised that DMA channel 4 be used for transfers where a software request is more appropriate (such as memory-to-memory transfers). In such an application, DREQ4 can be masked by software, freeing IRQ9# for other purposes.
EOP#	I/O	**END OF PROCESS:** As an output, this signal indicates that the current Requester access is the last access of the currently operating DMA channel. It is activated when Terminal Count is reached. As an input, it signals the DMA channel to terminate the current buffer and proceed to the next buffer, if one is available. This signal may be programmed as an asynchronous or synchronous input. EOP# must be connected to a pull-up resistor. This will prevent erroneous external requests for termination of a DMA process.
EDACK (0–2)	O	**ENCODED DMA ACKNOWLEDGE:** These signals contain the encoded acknowledgment of a request for DMA service by a peripheral. The binary code formed by the three signals indicates which channel is active. Channel 4 does not have a DMA acknowledge. The inactive state is indicated by the code 100. During a Requester access, EDACK presents the code for the active DMA channel. During a Target access, EDACK presents the inactive code 100.
IRQ (11–23)#	I	**INTERRUPT REQUEST:** These are active low interrupt request inputs. The inputs can be programmed to be edge or level sensitive. Interrupt priorities are programmable as either fixed or rotating. These inputs have weak internal pull-up resistors. Unused interrupt request inputs should be tied inactive externally.
INT	O	**INTERRUPT OUT:** INT signals that an interrupt request is pending.
CLKIN	I	**TIMER CLOCK INPUT:** This is the clock input signal to all of the 82370's programmable timers. It is independent of the system clock input (CLK2).
TOUT1/REF#	O	**TIMER 1 OUTPUT/REFRESH:** This pin is software programmable as either the direct output of Timer 1, or as the indicator of a refresh cycle in progress. As REF#, this signal is active during the memory read cycle which occurs during refresh.

Pin Descriptions (Continued)

Symbol	Type	Name and Function
TOUT2#/IRQ3#	I/O	**TIMER 2 OUTPUT/INTERRUPT REQUEST:** This is the inverted output of Timer 2. It is also connected directly to interrupt request 3. External hardware can use IRQ3# if Timer 2 is programmed as OUT = 0 (TOUT2# = 1).
TOUT3#	O	**TIMER 3 OUTPUT:** This is the inverted output of Timer 3.
READY#	I	**READY INPUT:** This active-low input indicates to the 82370 that the current bus cycle is complete. READY is sampled by the 82370 both while it is in the Master Mode, and while it is in the Slave Mode.
WSC (0–1)	I	**WAIT STATE CONTROL:** WSC0 and WSC1 are inputs used by the Wait-State Generator to determine the number of wait states required by the currently accessed memory or I/O. The binary code on these pins, combined with the M/IO# signal, selects an internal register in which a wait-state count is stored. The combination WSC = 11 disables the wait-state generator.
READYO#	O	**READY OUTPUT:** This is the synchronized output of the wait-state generator. It is also valid during CPU accesses to the 82370 in the Slave Mode when the 82370 requires wait states. READYO# should feed directly the processor's READY# input.
RESET	I	**RESET:** This synchronous input serves to initialize the state of the 82370 and provides basis for the CPURST output. RESET must be held active for at least 15 CLK2 cycles in order to guarantee the state of the 82370. After Reset, the 82370 is in the Slave Mode with all outputs except timers and interrupts in their inactive states. The state of the timers and interrupt controller must be initialized through software. This input must be active for the entire time required by the host processor to guarantee proper reset.
CHPSEL#	O	**CHIP SELECT:** This pin is driven active whenever the 82370 is addressed in a slave bus read or write cycle. It is also active during interrupt acknowledge cycles when the 82370 is driving the Data Bus. It can be used to control the local bus transceivers to prevent contention with the system bus.
CPURST	O	**CPU RESET:** CPURST provides a synchronized reset signal for the CPU. It is activated in the event of a software reset command, a processor shut-down detect, or a hardware reset via the RESET pin. The 82370 holds CPURST active for 62 clocks in response to either a software reset command or a shut-down detection. Otherwise CPURST reflects the RESET input.
V_{CC}		**POWER:** +5V input power.
V_{SS}		Ground Reference.

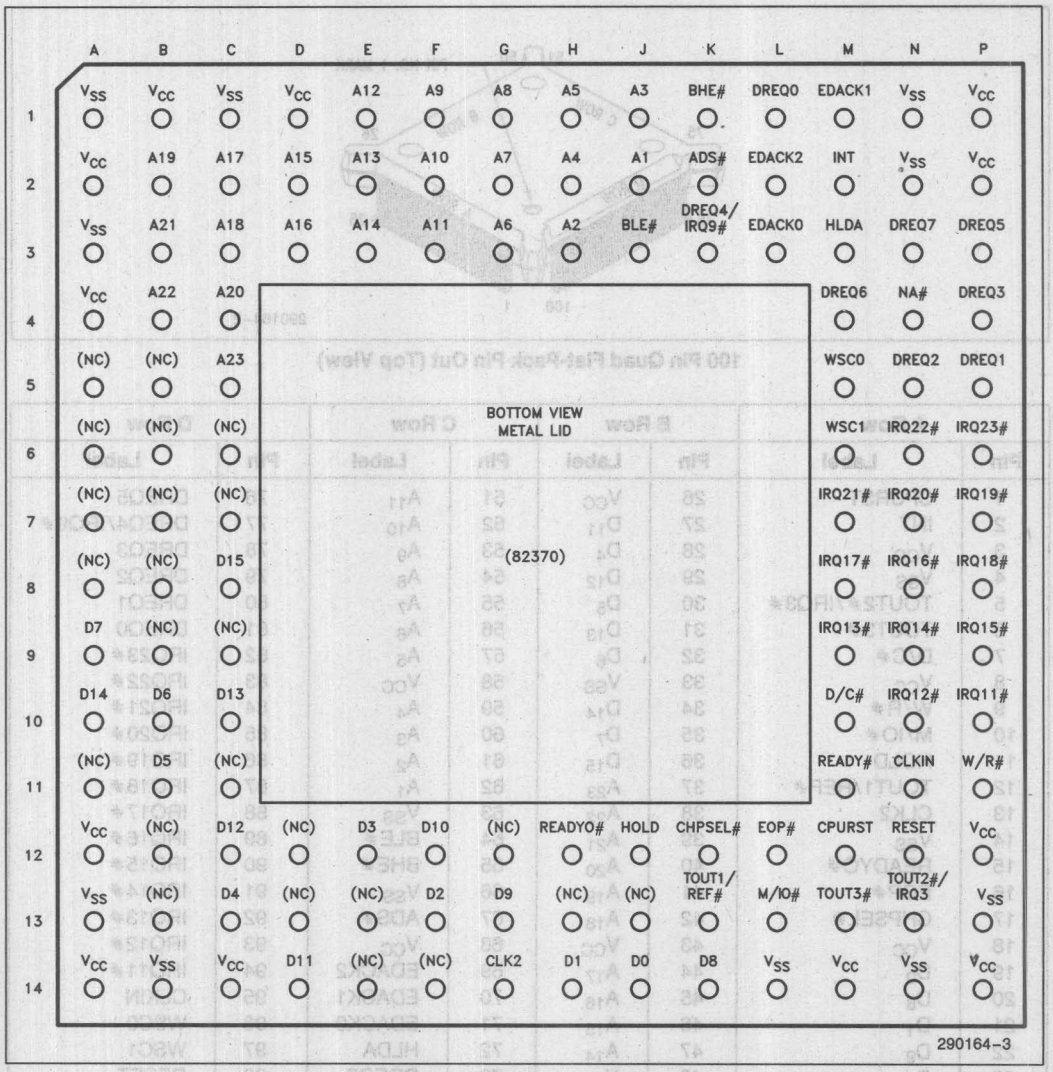
Table 1. Wait-State Select Inputs

Port Address	Wait-State Registers				Select Inputs	
	D7	D4	D3	D0	WSC1	WSC0
72H	MEMORY 0		I/O 0		0	0
73H	MEMORY 1		I/O 1		0	1
74H	MEMORY 2		I/O 2		1	0
	DISABLED				1	1
M/IO#	1		0			



100 Pin Quad Flat-Pack Pin Out (Top View)

A Row		B Row		C Row		D Row	
Pin	Label	Pin	Label	Pin	Label	Pin	Label
1	CPURST	26	V_{CC}	51	A_{11}	76	DREQ5
2	INT	27	D_{11}	52	A_{10}	77	DREQ4/IRQ9#
3	V_{CC}	28	D_4	53	A_9	78	DREQ3
4	V_{SS}	29	D_{12}	54	A_8	79	DREQ2
5	TOUT2#/IRQ3#	30	D_5	55	A_7	80	DREQ1
6	TOUT3#	31	D_{13}	56	A_6	81	DREQ0
7	D/C#	32	D_6	57	A_5	82	IRQ23#
8	V_{CC}	33	V_{SS}	58	V_{CC}	83	IRQ22#
9	W/R#	34	D_{14}	59	A_4	84	IRQ21#
10	M/IO#	35	D_7	60	A_3	85	IRQ20#
11	HOLD	36	D_{15}	61	A_2	86	IRQ19#
12	TOUT1/REF#	37	A_{23}	62	A_1	87	IRQ18#
13	CLK2	38	A_{22}	63	V_{SS}	88	IRQ17#
14	V_{SS}	39	A_{21}	64	BLE#	89	IRQ16#
15	READYO#	40	A_{20}	65	BHE#	90	IRQ15#
16	EOP#	41	A_{19}	66	V_{SS}	91	IRQ14#
17	CHPSEL#	42	A_{18}	67	ADS#	92	IRQ13#
18	V_{CC}	43	V_{CC}	68	V_{CC}	93	IRQ12#
19	D_0	44	A_{17}	69	EDACK2	94	IRQ11#
20	D_8	45	A_{16}	70	EDACK1	95	CLKIN
21	D_1	46	A_{15}	71	EDACK0	96	WSC0
22	D_9	47	A_{14}	72	HLDA	97	WSC1
23	D_2	48	V_{SS}	73	DREQ7	98	RESET
24	D_{10}	49	A_{13}	74	DREQ6	99	READY#
25	D_3	50	A_{12}	75	NA#	100	V_{SS}



82370 PGA Pinout

Pin	Label	Pin	Label	Pin	Label	Pin	Label
G14	CLK2	D14	D_{11}	L1	DREQ0	A2	V_{CC}
N12	RESET	F12	D_{10}	P6	IRQ23#	P2	V_{CC}
M12	CPURST	G13	D_9	N6	IRQ22#	A4	V_{CC}
C5	A_{23}	K14	D_8	M7	IRQ21#	A12	V_{CC}
B4	A_{22}	A9	D_7	N7	IRQ20#	P12	V_{CC}
B3	A_{21}	B10	D_6	P7	IRQ19#	A14	V_{CC}
C4	A_{20}	B11	D_5	P8	IRQ18#	C14	V_{CC}
B2	A_{19}	C13	D_4	M8	IRQ17#	M14	V_{CC}
C3	A_{18}	E12	D_3	N8	IRQ16#	P14	V_{CC}
C2	A_{17}	F13	D_2	P9	IRQ15#	A5	NC
D3	A_{16}	H14	D_1	N9	IRQ14#	B5	NC
D2	A_{15}	J14	D_0	M9	IRQ13#	A6	NC
E3	A_{14}	P11	W/R#	N10	IRQ12#	B6	NC
E2	A_{13}	L13	M/IO#	P10	IRQ11#	C6	NC
E1	A_{12}	K2	ADS#	M5	WSC0	A7	NC
F3	A_{11}	M10	D/C#	M6	WSC1	B7	NC
F2	A_{10}	N4	NA#	M13	TOUT3#	C7	NC
F1	A_9	M11	READY#	N13	TOUT2#/IRQ3#	A8	NC
G1	A_8	H12	READYO#	K13	TOUT1/REF#	B8	NC
G2	A_7	J12	HOLD	N11	CLKIN	B9	NC
G3	A_6	M3	HLDA	A1	V_{SS}	C9	NC
H1	A_5	M2	INT	C1	V_{SS}	A11	NC
H2	A_4	L12	EOP#	N1	V_{SS}	B12	NC
J1	A_3	L2	EDACK2	N2	V_{SS}	C11	NC
H3	A_2	M1	EDACK1	A3	V_{SS}	D12	NC
J2	A_1	L3	EDACK0	A13	V_{SS}	G12	NC
J3	BLE#	N3	DREQ7	P13	V_{SS}	B13	NC
K1	BHE#	M4	DREQ6	B14	V_{SS}	D13	NC
K12	CHPSEL#	P3	DREQ5	L14	V_{SS}	E13	NC
C8	D_{15}	K3	DREQ4/IRQ9#	N14	V_{SS}	H13	NC
A10	D_{14}	P4	DREQ3	B1	V_{CC}	J13	NC
C10	D_{13}	N5	DREQ2	D1	V_{CC}	E14	NC
C12	D_{12}	P5	DREQ1	P1	V_{CC}	F14	NC

1.0 FUNCTIONAL OVERVIEW

The 82370 contains several independent functional modules. The following is a brief discussion of the components and features of the 82370. Each module has a corresponding detailed section later in this data sheet. Those sections should be referred to for design and programming information.

1.1 82370 Architecture

The 82370 is comprised of several computer system functions that are normally found in separate LSI and VLSI components. These include: a high-performance, eight-channel, 32-bit Direct Memory Access Controller; a 20-level Programmable Interrupt Controller which is a superset of the 82C59A; four 16-bit Programmable Interval Timers which are functionally equivalent to the 82C54 timers; a DRAM Refresh Controller; a Programmable Wait State Generator; and system reset logic. The interface to the 82370 is optimized for high-performance operation with the 80376 microprocessor.

The 82370 operates directly on the 80376 bus. In the Slave Mode, it monitors the state of the processor at all times and acts or idles according to the commands of the host. It monitors the address pipeline status and generates the programmed number of wait states for the device being accessed. The 82370 also has logic to the reset of the 80376 via hardware or software reset requests and processor shutdown status.

9

After a system reset, the 82370 is in the Slave Mode. It appears to the system as an I/O device. It becomes a bus master when it is performing DMA transfers.

To maintain compatibility with existing software, the registers within the 82370 are accessed as bytes. If the internal logic of the 82370 requires a delay before another access by the processor, wait states are automatically inserted into the access cycle. This allows the programmer to write initialization routines, etc. without regard to hardware recovery times.

Figure 1-1 shows the basic architectural components of the 82370. The following sections briefly discuss the architecture and function of each of the distinct sections of the 82370.

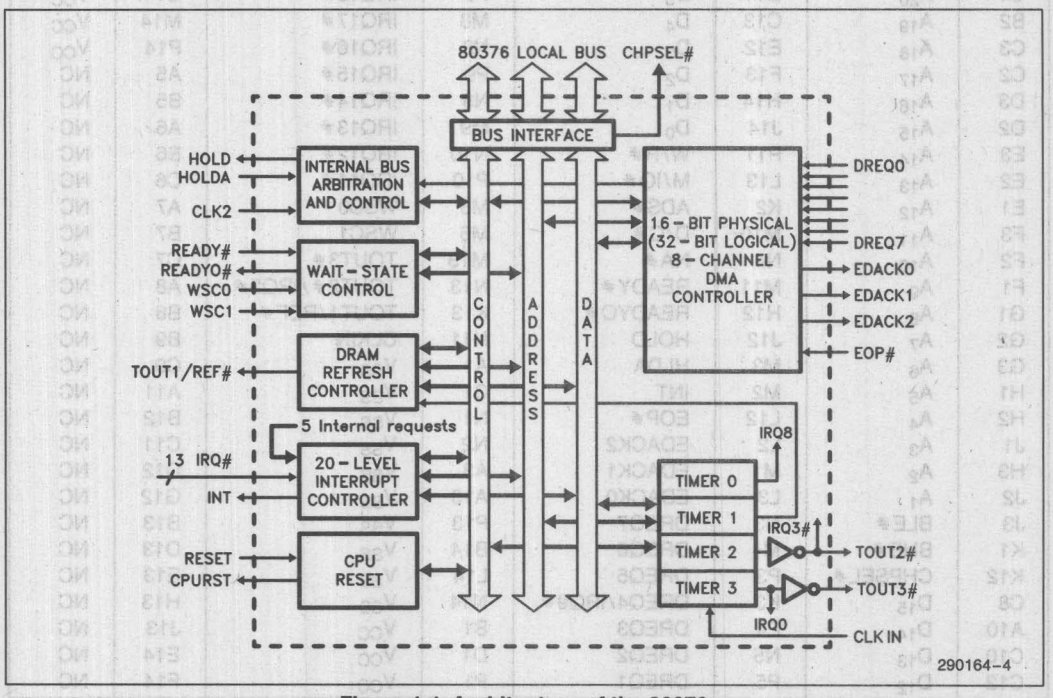


Figure 1-1. Architecture of the 82370

1.1.1 DMA CONTROLLER

The 82370 contains a high-performance, 8-channel DMA Controller. It provides a 32-bit internal data path. Through its 16-bit external physical data bus, it is capable of transferring data in any combination of bytes, words and double-words. The addresses of both source and destination can be independently incremented, decremented or held constant, and cover the entire 16-bit physical address space of the 80376. It can disassemble and assemble non-aligned data via a 32-bit internal temporary data storage register. Data transferred between devices of different data path widths can also be assembled and disassembled using the internal temporary data storage register. The DMA Controller can also transfer aligned data between I/O and memory on the fly, allowing data transfer rates up to 16 megabytes per second for an 82370 operating at 16 MHz. Figure 1-2 illustrates the functional components of the DMA Controller.

There are twenty-four general status and command registers in the 82370 DMA Controller. Through these registers any of the channels may be programmed into any of the possible modes. The operating modes of any one channel are independent of the operation of the other channels.

Each channel has three programmable registers which determine the location and amount of data to be transferred:

Byte Count Register— Number of bytes to transfer. (24-bits)

Requester Register — Byte Address of memory or peripheral which is requesting DMA service. (24-bits)

Target Register — Byte Address of peripheral or memory which will be accessed. (24-bits)

There are also port addresses which, when accessed, cause the 82370 to perform specific functions. The actual data written doesn't matter, the act of writing to the specific address causes the command to be executed. The commands which operate in this mode are: Master Clear, Clear Terminal Count Interrupt Request, Clear Mask Register, and Clear Byte Pointer Flip-Flop.

DMA transfers can be done between all combinations of memory and I/O; memory-to-memory, memory-to-I/O, I/O-to-memory, and I/O-to-I/O. DMA service can be requested through software and/or hardware. Hardware DMA acknowledge signals are available for all channels (except channel 4) through an encoded 3-bit DMA acknowledge bus (EDACK0–2).

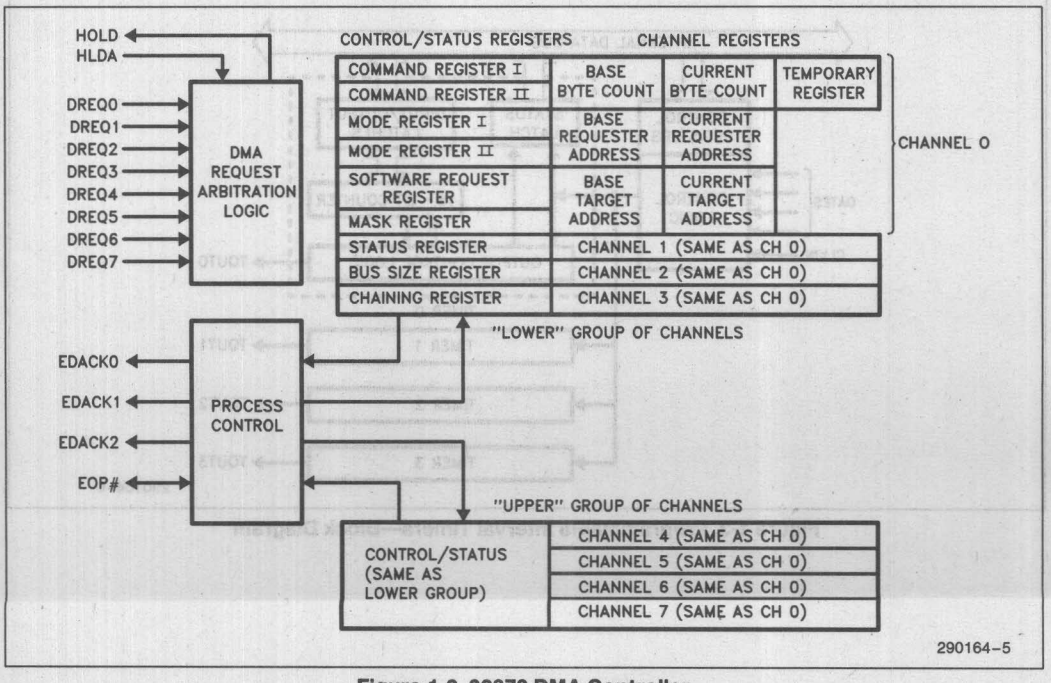


Figure 1-2. 82370 DMA Controller

The 82370 DMA Controller transfers blocks of data (buffers) in three modes: Single Buffer, Buffer Auto-Initialize, and Buffer Chaining. In the Single Buffer Process, the 82370 DMA Controller is programmed to transfer one particular block of data. Successive transfers then require reprogramming of the DMA channel. Single Buffer transfers are useful in systems where it is known at the time the transfer begins what quantity of data is to be transferred, and there is a contiguous block of data area available.

The Buffer Auto-Initialize Process allows the same data area to be used for successive DMA transfers without having to reprogram the channel.

The Buffer Chaining Process allows a program to specify a list of buffer transfers to be executed. The 82370 DMA Controller, through interrupt routines, is reprogrammed from the list. The channel is reprogrammed for a new buffer before the current buffer transfer is complete. This pipelining of the channel programming process allows the system to allocate non-contiguous blocks of data storage space, and transfer all of the data with one DMA process. The buffers that make up the chain do not have to be in contiguous locations.

Channel priority can be fixed or rotating. Fixed priority allows the programmer to define the priority of DMA channels based on hardware or other fixed parameters. Rotating priority is used to provide peripherals access to the bus on a shared basis.

With fixed priority, the programmer can set any channel to have the current lowest priority. This allows the user to reset or manually rotate the priority schedule without reprogramming the command registers.

1.1.2 PROGRAMMABLE INTERVAL TIMERS

Four 16-bit programmable interval timers reside within the 82370. These timers are identical in function to the timers in the 82C54 Programmable Interval Timer. All four of the timers share a common clock input which can be independent of the system clock. The timers are capable of operating in six different modes. In all of the modes, the current count can be latched and read by the 80376 at any time, making these very versatile event timers. Figure 1-3 shows the functional components of the Programmable Interval Timers.

The outputs of the timers are directed to key system functions, making system design simpler. Timer 0 is routed directly to an interrupt input and is not available externally. This timer would typically be used to generate time-keeping interrupts.

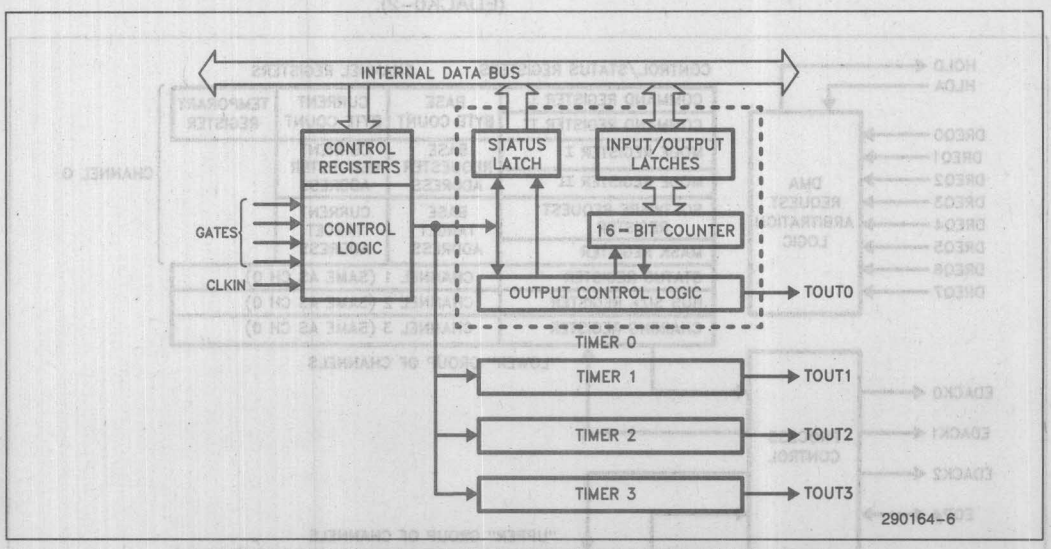


Figure 1-3. Programmable Interval Timers—Block Diagram

Timers 1 and 2 have outputs which are available for general timer/counter purposes as well as special functions. Timer 1 is routed to the refresh control logic to provide refresh timing. Timer 2 is connected to an interrupt request input to provide other timer functions. Timer 3 is a general purpose timer/counter whose output is available to external hardware. It is also connected internally to the interrupt request which defaults to the highest priority (IRQ0).

1.1.3 INTERRUPT CONTROLLER

The 82370 has the equivalent of three enhanced 82C59A Programmable Interrupt Controllers. These controllers can all be operated in the Master Mode, but the priority is always as if they were cascaded. There are 15 interrupt request inputs provided for the user, all of which can be inputs from external slave interrupt controllers. Cascading 82C59As to these request inputs allows a possible total of 120 external interrupt requests. Figure 1-4 is a block diagram of the 82370 Interrupt Controller.

Each of the interrupt request inputs can be individually programmed with its own interrupt vector, allowing more flexibility in interrupt vector mapping than was available with the 82C59A. An interrupt is provided to alert the system that an attempt is being made to program the vectors in the method of the 82C59A. This provides compatibility of existing software that used the 82C59A or 8259A with new designs using the 82370.

In the event of an unrequested or otherwise erroneous interrupt acknowledge cycle, the 82370 Interrupt Controller issues a default vector. This vector, programmed by the system software, will alert the system of unsolicited interrupts of the 80376.

The functions of the 82370 Interrupt Controller are identical to the 82C59A, except in regards to programming the interrupt vectors as mentioned above. Interrupt request inputs are programmable as either edge or level triggered and are software maskable. Priority can be either fixed or rotating and interrupt requests can be nested.

Enhancements are added to the 82370 for cascading external interrupt controllers. Master to Slave handshaking takes place on the data bus, instead of dedicated cascade lines.

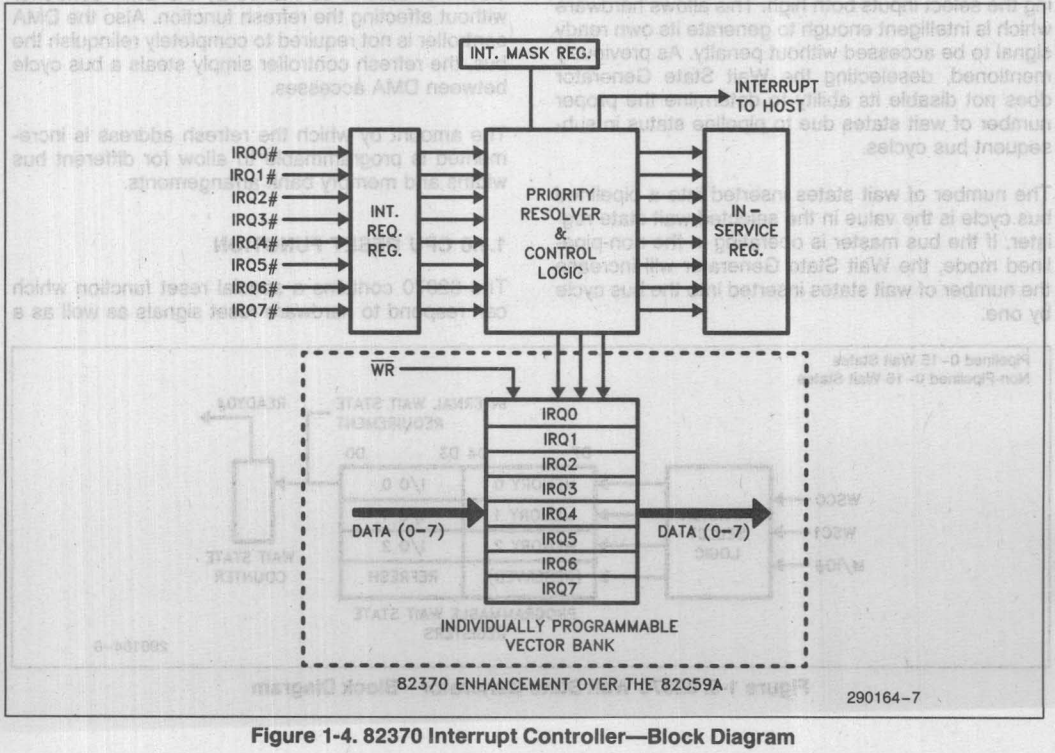


Figure 1-4. 82370 Interrupt Controller—Block Diagram

1.1.4 WAIT STATE GENERATOR

The Wait State Generator is a programmable READY generation circuit for the 80376 bus. A peripheral requiring wait states can request the Wait State Generator to hold the processor's READY input inactive for a predetermined number of bus states. Six different wait state counts can be programmed into the Wait State Generator by software; three for memory accesses and three for I/O accesses. A block diagram of the 82370 Wait State Generator is shown in Figure 1-5.

The peripheral being accessed selects the required wait state count by placing a code on a 2-bit wait state select bus. This code along with the M/IO# signal from the bus master is used to select one of six internal 4-bit wait state registers which has been programmed with the desired number of wait states. From zero to fifteen wait states can be programmed into the wait state registers. The Wait State generator tracks the state of the processor or current bus master at all times, regardless of which device is the current bus master and regardless of whether or not the wait state generator is currently active.

The 82370 Wait State Generator is disabled by making the select inputs both high. This allows hardware which is intelligent enough to generate its own ready signal to be accessed without penalty. As previously mentioned, deselecting the Wait State Generator does not disable its ability to determine the proper number of wait states due to pipeline status in subsequent bus cycles.

The number of wait states inserted into a pipelined bus cycle is the value in the selected wait state register. If the bus master is operating in the non-pipelined mode, the Wait State Generator will increase the number of wait states inserted into the bus cycle by one.

On reset, the Wait State Generator's registers are loaded with the value FFH, giving the maximum number of wait states for any access in which the wait state select inputs are active.

1.1.5 DRAM REFRESH CONTROLLER

The 82370 DRAM Refresh Controller consists of a 24-bit refresh address counter and bus arbitration logic. The output of Timer 1 is used to periodically request a refresh cycle. When the controller receives the request, it requests access to the system bus through the HOLD signal. When bus control is acknowledged by the processor or current bus master, the refresh controller executes a memory read operation at the address currently in the Refresh Address Register. At the same time, it activates a refresh signal (REF#) that the memory uses to force a refresh instead of a normal read. Control of the bus is transferred to the processor at the completion of this cycle. Typically a refresh cycle will take six clock cycles to execute on an 80376 bus.

The 82370 DRAM Refresh Controller has the highest priority when requesting bus access and will interrupt any active DMA process. This allows large blocks of data to be moved by the DMA controller without affecting the refresh function. Also the DMA controller is not required to completely relinquish the bus, the refresh controller simply steals a bus cycle between DMA accesses.

The amount by which the refresh address is incremented is programmable to allow for different bus widths and memory bank arrangements.

1.1.6 CPU RESET FUNCTION

The 82370 contains a special reset function which can respond to hardware reset signals as well as a

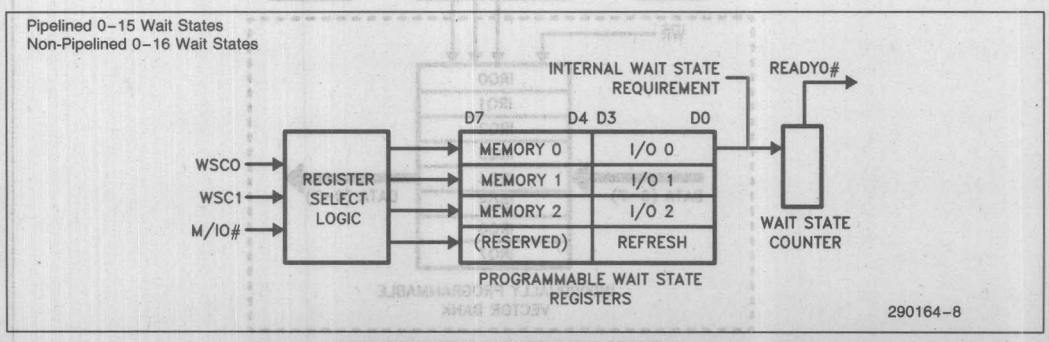


Figure 1-5. 82370 Wait State Generator—Block Diagram

software reset command. The circuit will hold the 80376's RESET line active while an external hardware reset signal is present at its RESET input. It can also reset the 80376 processor as the result of a software command. The software reset command causes the 82370 to hold the processor's RESET line active for a minimum of 62 clock cycles. The 80376 requires that its RESET line be held active for a minimum of 80 clock cycles to re-initialize. For a more detailed explanation and solution, see Appendix D (System Notes).

The 82370 can be programmed to sense the shutdown detect code on the status lines from the 80376. If the Shutdown Detect function is enabled, the 82370 will automatically reset the processor. A diagnostic register is available which can be used to determine the cause of reset.

1.1.7 REGISTER MAP RELOCATION

After a hardware reset, the internal registers of the 82370 are located in I/O space beginning at port address 0000H. The map of the 82370's registers is relocatable via a software command. The default mapping places the 82370 between I/O addresses 0000H and 00DBH. The relocation register allows this map to be moved to any even 256-byte boundary in the processor's 16-bit I/O address space or any even 64 kbyte boundary in the 24-bit memory address space.

1.2 Host Interface

The 82370 is designed to operate efficiently on the local bus of an 80376 microprocessor. The control signals of the 82370 are identical in function to those of the 80376. As a slave, the 82370 operates with all of the features available on the 80376 bus. When the 82370 is in the Master Mode, it looks identical to an 80376 to the connected devices.

The 82370 monitors the bus at all times, and determines whether the current bus cycle is a pipelined or non-pipelined access. All of the status signals of the processor are monitored.

The control, status, and data registers within the 82370 are located at fixed addresses relative to each other, but the group can be relocated to either memory or I/O space and to different locations within those spaces.

As a Slave device, the 82370 monitors the control/status lines of the CPU. The 82370 will generate all *of the wait states it needs whenever it is accessed.* This allows the programmer the freedom of accessing 82370 registers without having to insert NOPs in the program to wait for slower 82370 internal registers.

The 82370 can determine if a current bus cycle is a pipelined or a non-pipelined cycle. It does this by monitoring the ADS#, NA# and READY# signals and thereby keeping track of the current state of the 80376.

As a bus master, the 82370 looks like an 80376 to the rest of the system. This enables the designer greater flexibility in systems which include the 82370. The designer does not have to alter the interfaces of any peripherals designed to operate with the 80376 to accommodate the 82370. The 82370 will access any peripherals on the bus in the same manner as the 80376, including recognizing pipelined bus cycles.

The 82370 is accessed as an 8-bit peripheral. The 80376 places the data of all 8-bit accesses either on D(0–7) or D(8–15). The 82370 will only accept data on these lines when in the Slave Mode. When in the Master Mode, the 82370 is a full 16-bit machine, sending and receiving data in the same manner as the 80376.

2.0 80376 HOST INTERFACE

The 82370 contains a set of interface signals to operate efficiently with the 80376 host processor. These signals were designed so that minimal hardware is needed to connect the 82370 to the 80376. Figure 2-1 depicts a typical system configuration with the 80376 processor. As shown in the diagram, the 82370 is designed to interface directly with the 80376 bus.

Since the 82370 resides on the opposite side of the data bus transceivers with respect to the rest of the system peripherals, it is important to note that the transceivers should be controlled so that contention between the data bus transceivers and the 82370 will not occur. In order to ease the implementation of this, the 82370 activates the CHPSEL# signal which indicates that the 82370 has been addressed and may output data. This signal should be included in the direction and enable control logic of the transceiver. When any of the 82370 internal registers are read, the data bus transceivers should be disabled so that only the 82370 will drive the local bus.

This section describes the basic bus functions of the 82370 to show how this device interacts with the 80376 processor. Other signals which are not directly related to the host interface will be discussed in their associated functional block description.

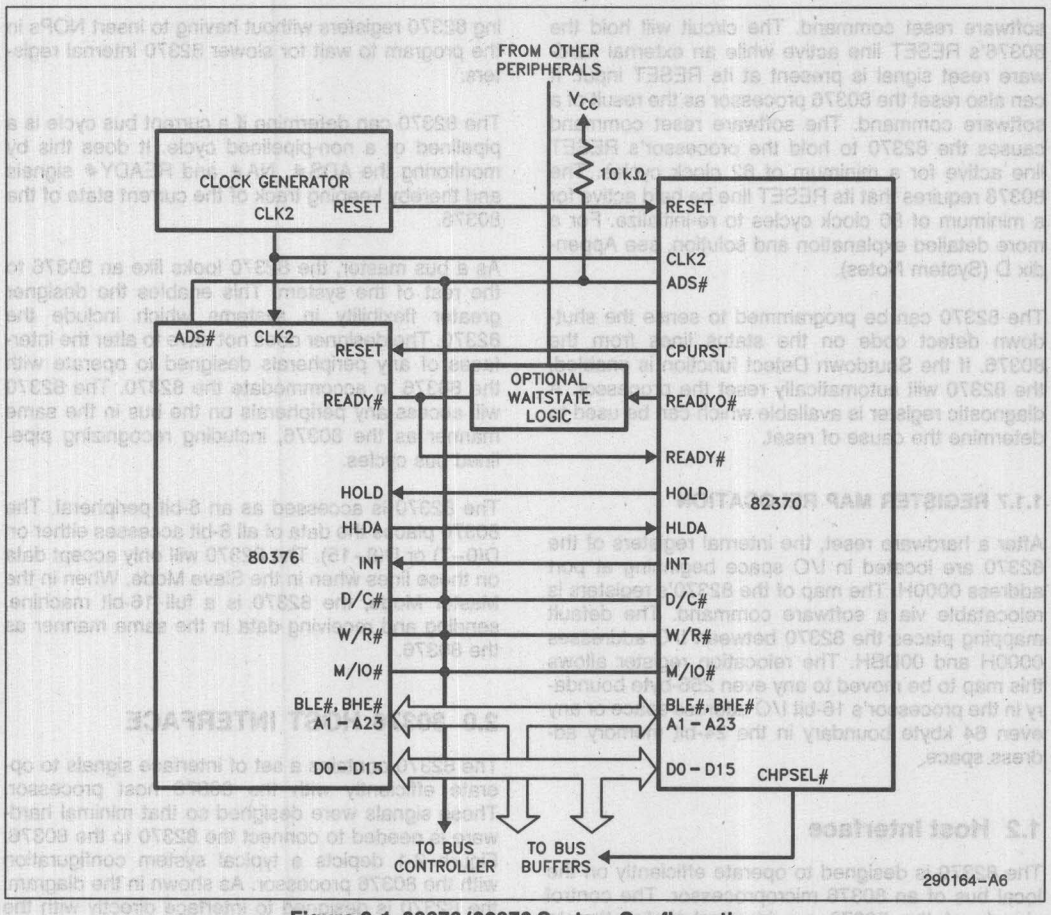


Figure 2-1. 80376/82370 System Configuration

2.1 Master and Slave Modes

At any time, the 82370 acts as either a Slave device or a Master device in the system. Upon reset, the 82370 will be in the Slave Mode. In this mode, the 80376 processor can read/write into the 82370 internal registers. Initialization information may be programmed into the 82370 during Slave Mode.

When DMA service (including DRAM Refresh Cycles generated by the 82370) is requested, the 82370 will request and subsequently get control of the 80376 local bus. This is done through the HOLD and HLDA (Hold Acknowledge) signals. When the 80376 processor responds by asserting the HLDA signal, the 82370 will switch into Master Mode and perform DMA transfers. In this mode, the 82370 is the bus master of the system. It can read/write data from/to memory and peripheral devices. The 82370 will return to the Slave Mode upon completion of DMA transfers, or when HLDA is negated.

2.2 80376 Interface Signals

As mentioned in the Architecture section, the Bus Interface module of the 82370 (see Figure 1-1) contains signals that are directly connected to the 80376 host processor. This module has separate

16-bit Data and 24-bit Address busses. Also, it has additional control signals to support different bus operations on the system. By residing on the 80376 local bus, the 82370 shares the same address, data and control lines with the processor. The following subsections discuss the signals which interface to the 80376 host processor.

2.2.1 CLOCK (CLK2)

The CLK2 input provides fundamental timing for the 82370. It is divided by two internally to generate the 82370 internal clock. Therefore, CLK2 should be driven with twice the 80376's frequency. In order to maintain synchronization with the 80376 host processor, the 82370 and the 80376 should share a common clock source.

The internal clock consists of two phases: PHI1 and PHI2. Each CLK2 period is a phase of the internal clock. PHI2 is usually used to sample input and set up internal signals and PHI1 is for latching internal data. Figure 2-2 illustrates the relationship of CLK2 and the 82370 internal clock signals. The CPURST signal generated by the 82370 guarantees that the 80376 will wake up in phase with PHI1.

2.2.2 DATA BUS (D_0–D_{15})

This 16-bit three-state bidirectional bus provides a general purpose data path between the 82370 and the system. These pins are tied directly to the corresponding Data Bus pins of the 80376 local bus. The Data Bus is also used for interrupt vectors generated by the 82370 in the Interrupt Acknowledge cycle.

During Slave I/O operations, the 82370 expects a single byte to be written or read. When the 80376 host processor writes into the 82370, either D_0–D_7 or D_8–D_{15} will be latched into the 82370, depending upon whether Byte Enable bit BLE# is 0 or 1 (see Table 2-1). When the 80376 host processor reads from the 82370, the single byte data will be duplicated twice on the Data Bus; i.e. on D_0–D_7 and D_8–D_{15}.

During Master Mode, the 82370 can transfer 16-, and 8-bit data between memory (or I/O devices) and I/O devices (or memory) via the Data Bus.

2.2.3 ADDRESS BUS (A_{23}–A_1)

These three-state bidirectional signals are connected directly to the 80376 Address Bus. In the Slave Mode, they are used as input signals so that the processor can address the 82370 internal ports/registers. In the Master Mode, they are used as output signals by the 82370 to address memory and peripheral devices. The Address Bus is capable of addressing 16 Mbytes of physical memory space (000000H to FFFFFFH), and 64 Kbytes of I/O addresses.

2.2.4 BYTE ENABLE (BHE#, BLE#)

The Byte Enable pins BHE# and BLE# select the specific byte(s) in the word addressed by A_1–A_{23}. During Master Mode operation, it is used as an output by the 82370 to address memory and I/O locations. The definition of BHE# and BLE# is further illustrated in Table 2-1.

NOTE:
The 82370 will activate BHE# when output in Master Mode. For a more detailed explanation and its solutions, see Appendix D (System Notes).

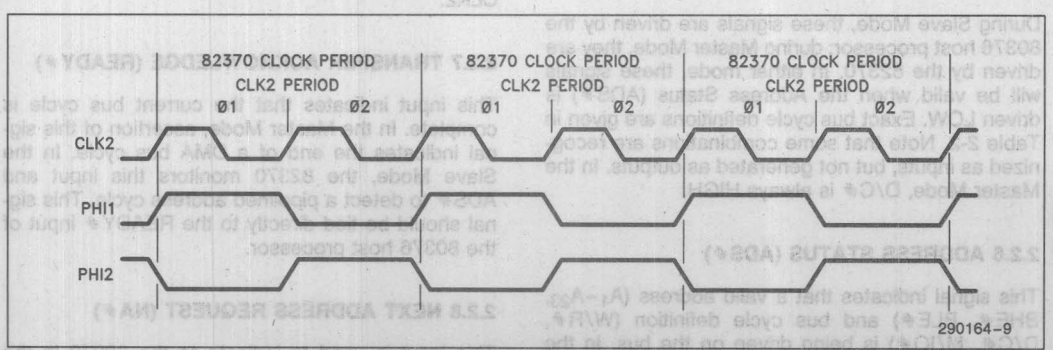


Figure 2-2. CLK2 and 82370 Internal Clock

As an output (Master Mode):

Table 2-1. Byte Enable Signals

BHE#	BLE#	Byte to be Accessed Relative to A_{23}–A_1	Logical Byte Presented on Data Bus During WRITE Only* D_{15}–D_8	D_7–D_0
0	0	0, 1	B	A
0	1	1	A	A
1	0	0	U	A
1	1	(Not Used)		

U = Undefined
A = Logical D_0–D_7
B = Logical D_8–D_{15}

***NOTE:**
Actual number of bytes accessed depends upon the programmed data path width.

Table 2-2. Bus Cycle Definition

M/IO#	D/C#	W/R#	As INPUTS	As OUTPUTS
0	0	0	Interrupt Acknowledge	NOT GENERATED
0	0	1	UNDEFINED	NOT GENERATED
0	1	0	I/O Read	I/O Read
0	1	1	I/O Write	I/O Write
1	0	0	UNDEFINED	NOT GENERATED
1	0	1	HALT if A_1 = 1 SHUTDOWN if A_1 = 0	NOT GENERATED
1	1	0	Memory Read	Memory Read
1	1	1	Memory Write	Memory Write

2.2.5 BUS CYCLE DEFINITION SIGNALS (D/C#, W/R#, M/IO#)

These three-state bidirectional signals define the type of bus cycle being performed. W/R# distinguishes between write and read cycles. D/C# distinguishes between processor data and control cycles. M/IO# distinguishes between memory and I/O cycles.

During Slave Mode, these signals are driven by the 80376 host processor; during Master Mode, they are driven by the 82370. In either mode, these signals will be valid when the Address Status (ADS#) is driven LOW. Exact bus cycle definitions are given in Table 2-2. Note that some combinations are recognized as inputs, but not generated as outputs. In the Master Mode, D/C# is always HIGH.

2.2.6 ADDRESS STATUS (ADS#)

This signal indicates that a valid address (A_1–A_{23}, BHE#, BLE#) and bus cycle definition (W/R#, D/C#, M/IO#) is being driven on the bus. In the Master Mode, it is driven by the 82370 as an output. In the Slave Mode, this signal is monitored as an input by the 82370. By the current and past status of ADS# and the READY# input, the 82370 is able to determine, during Slave Mode, if the next bus cycle is a pipelined address cycle. ADS# is asserted during T1 and T2P bus states (see Bus State Definition).

NOTE:
ADS# must be qualified with the rising edge of CLK2.

2.2.7 TRANSFER ACKNOWLEDGE (READY#)

This input indicates that the current bus cycle is complete. In the Master Mode, assertion of this signal indicates the end of a DMA bus cycle. In the Slave Mode, the 82370 monitors this input and ADS# to detect a pipelined address cycle. This signal should be tied directly to the READY# input of the 80376 host processor.

2.2.8 NEXT ADDRESS REQUEST (NA#)

This input is used to indicate to the 82370 in the Master Mode that the system is requesting address

pipelining. When driven LOW by either memory or peripheral devices during Master Mode, it indicates that the system is prepared to accept a new address and bus cycle definition signals from the 82370 before the end of the current bus cycle. If this input is active when sampled by the 82370, the next address is driven onto the bus, provided a bus request is already pending internally.

This input pin is monitored only in the Master Mode. In the Slave Mode, the 82370 uses the ADS# and READY# signals to determine address pipelining cycles, and NA# will be ignored.

2.2.9 RESET (RESET, CPURST)

RESET

This synchronous input suspends any operation in progress and places the 82370 in a known initial state. Upon reset, the 82370 will be in the Slave Mode waiting to be initialized by the 80376 host processor. The 82370 is reset by asserting RESET for 15 or more CLK2 periods. When RESET is asserted, all other input pins are ignored, and all other bus pins are driven to an idle bus state as shown in Table 2-3. The 82370 will determine the phase of its internal clock following RESET going inactive.

RESET is level-sensitive and must be synchronous to the CLK2 signal. The RESET setup and hold time requirements are shown in Figure 2-3.

Table 2-3. Output Signals Following RESET

Signal	Level
A_1–A_{23}, D_0–D_{15}, BHE#, BLE#	Float
D/C#, W/R#, M/IO#, ADS#	Float
READYO#	'1'
EOP#	'1' (Weak Pull-UP)
EDACK2–EDACK0	'100'
HOLD	'0'
INT	UNDEFINED*
TOUT1/REF#, TOUT2#/IRQ3#, TOUT3#	UNDEFINED*
CPURST	'0'
CHPSEL#	'1'

***NOTE:**
The Interrupt Controller and Programmable Interval Timer are initialized by software commands.

CPURST

This output signal is used to reset the 80376 host processor. It will go active (HIGH) whenever one of the following events occurs: a) 82370's RESET input is active; b) a software RESET command is issued to the 82370; or c) when the 82370 detects a processor Shutdown cycle and when this detection feature is enabled (see CPU Reset and Shutdown Detect). When activated, CPURST will be held active for 62 clocks. The timing of CPURST is such that the 80376 processor will be in synchronization with the 82370. This timing is shown in Figure 2-4.

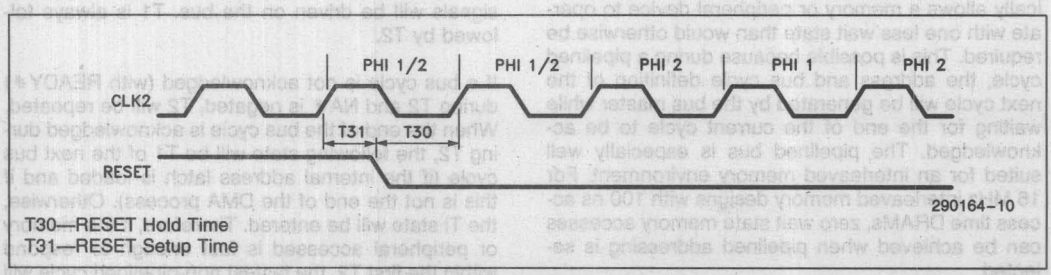


Figure 2-3. RESET Timing

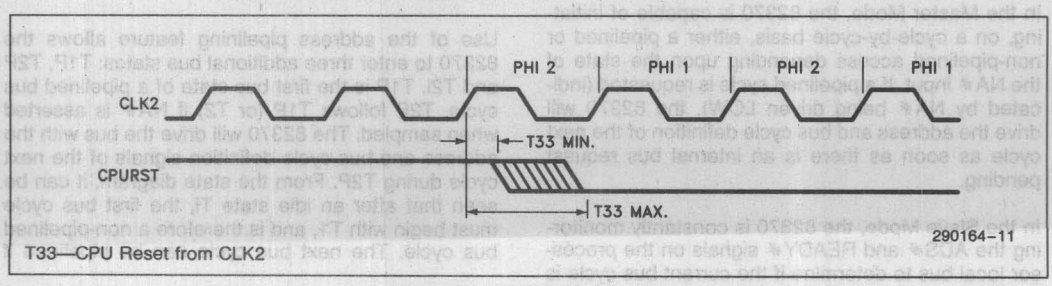


Figure 2-4. CPURST Timing

2.2.10 INTERRUPT OUT (INT)

This output pin is used to signal the 80376 host processor that one or more interrupt requests (either internal or external) are pending. The processor is expected to respond with an Interrupt Acknowledge cycle. This signal should be connected directly to the Maskable Interrupt Request (INTR) input of the 80376 host processor.

2.3 82370 Bus Timing

The 82370 internally divides the CLK2 signal by two to generate its internal clock. Figure 2-2 showed the relationship of CLK2 and the internal clock which consists of two phases: PHI1 and PHI2. Each CLK2 period is a phase of the internal clock.

In the 82370, whether it is in the Master or Slave Mode, the shortest time unit of bus activity is a bus state. A bus state, which is also referred as a 'T-state', is defined as one 82370 PHI2 clock period (i.e. two CLK2 periods). Recall in Table 2-2 various types of bus cycles in the 82370 are defined by the M/IO#, D/C# and W/R# signals. Each of these bus cycles is composed of two or more bus states. The length of a bus cycle depends on when the READY# input is asserted (i.e. driven LOW).

2.3.1 ADDRESS PIPELINING

The 82370 supports Address Pipelining as an option in both the Master and Slave Mode. This feature typically allows a memory or peripheral device to operate with one less wait state than would otherwise be required. This is possible because during a pipelined cycle, the address and bus cycle definition of the next cycle will be generated by the bus master while waiting for the end of the current cycle to be acknowledged. The pipelined bus is especially well suited for an interleaved memory environment. For 16 MHz interleaved memory designs with 100 ns access time DRAMs, zero wait state memory accesses can be achieved when pipelined addressing is selected.

In the Master Mode, the 82370 is capable of initiating, on a cycle-by-cycle basis, either a pipelined or non-pipelined access depending upon the state of the NA# input. If a pipelined cycle is requested (indicated by NA# being driven LOW), the 82370 will drive the address and bus cycle definition of the next cycle as soon as there is an internal bus request pending.

In the Slave Mode, the 82370 is constantly monitoring the ADS# and READY# signals on the processor local bus to determine if the current bus cycle is a pipelined cycle. If a pipelined cycle is detected, the 82370 will request one less wait state from the processor if the Wait State Generator feature is selected. On the other hand, during an 82370 internal register access in a pipelined cycle, it will make use of the advance address and bus cycle information. In all cases, Address Pipelining will result in a savings of one wait state.

2.3.2 MASTER MODE BUS TIMING

When the 82370 is in the Master Mode, it will be in one of six bus states. Figure 2-5 shows the complete bus state diagram of the Master Mode, including pipelined address states. As seen in the figure, the 82370 state diagram is very similar to that of the 80376. The major difference is that in the 82370, there is no Hold state. Also, in the 82370, the conditions for some state transitions depend upon whether it is the end of a DMA process.

NOTE:
The term 'end of a DMA process' is loosely defined here. It depends on the DMA modes of operation as well as the state of the EOP# and DREQ inputs. This is expained in detail in section 3—DMA Controller.

The 82370 will enter the idle state, Ti, upon RESET and whenever the internal address is not available at the end of a DMA cycle or at the end of a DMA process. When address pipelining is not used (NA# is not asserted), a new bus cycle always begins with state T1. During T1, address and bus cycle definition signals will be driven on the bus. T1 is always followed by T2.

If a bus cycle is not acknowledged (with READY#) during T2 and NA# is negated, T2 will be repeated. When the end of the bus cycle is acknowledged during T2, the following state will be T1 of the next bus cycle (if the internal address latch is loaded and if this is not the end of the DMA process). Otherwise, the Ti state will be entered. Therefore, if the memory or peripheral accessed is fast enough to respond within the first T2, the fastest non-pipelined cycle will take one T1 and one T2 state.

Use of the address pipelining feature allows the 82370 to enter three additional bus states: T1P, T2P and T2i. T1P is the first bus state of a pipelined bus cycle. T2P follows T1P (or T2) if NA# is asserted when sampled. The 82370 will drive the bus with the address and bus cycle definition signals of the next cycle during T2P. From the state diagram, it can be seen that after an idle state Ti, the first bus cycle must begin with T1, and is therefore a non-pipelined bus cycle. The next bus cycle can be pipelined if

NA# is asserted and the previous bus cycle ended in a T2P state. Once the 82370 is in a pipelined cycle and provided that NA# is asserted in subsequent cycles, the 82370 will be switching between T1P and T2P states. If the end of the current bus cycle is not acknowledged by the READY# input, the 82370 will extend the cycle by adding T2P states. The fastest pipelined cycle will consist of one T1P and one T2P state.

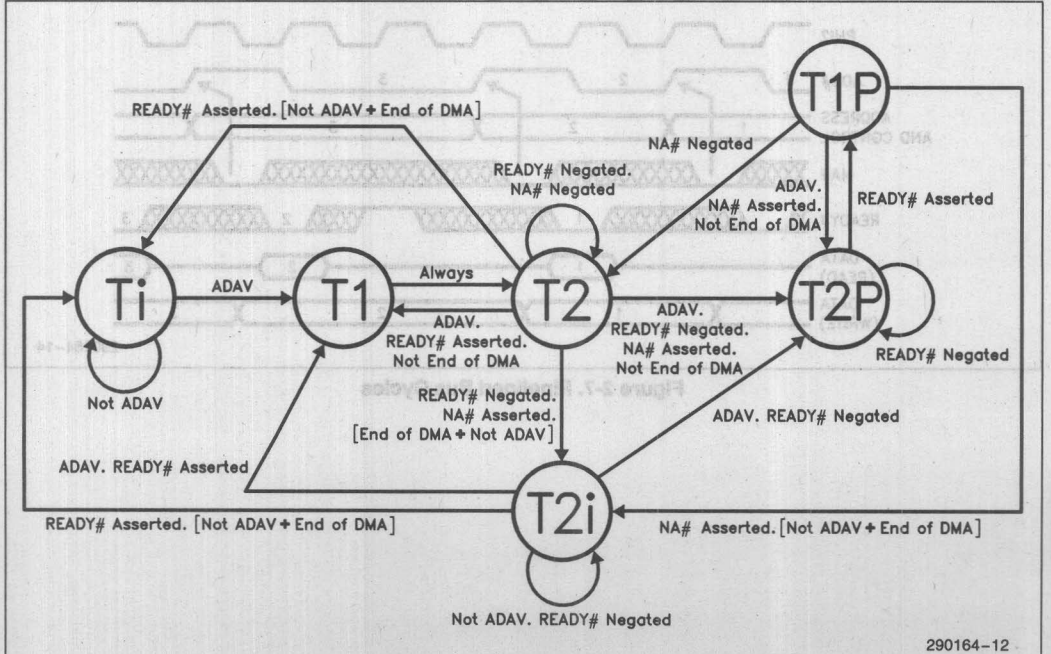
The 82370 will enter state T2i when NA# is asserted and when one of the following two conditions occurs. The first condition is when the 82370 is in state T2. T2i will be entered if READY# is not asserted and there is no next address available. This situation is similar to a wait state. The 82370 will stay in T2i for as long as this condition exists. The second condition which will cause the 82370 to enter T2i is when the 82370 is in state T1P. Before going to state T2P, the 82370 needs to wait in state T2i until the next address is available. Also, in both cases, if the DMA process is complete, the 82370 will enter the T2i state in order to finish the current DMA cycle.

Figure 2-6 is a timing diagram showing non-pipelined bus accesses in the Master Mode. Figure 2-7 shows the timing of pipelined accesses in the Master Mode.

2.3.3 SLAVE MODE BUS TIMING

Figure 2-8 shows the Slave Mode bus timing in both pipelined and non-pipelined cycles when the 82370 is being accessed. Recall that during Slave Mode, the 82370 will constantly monitor the ADS# and READY# signals to determine if the next cycle is pipelined. In Figure 2-8, the first cycle is non-pipelined and the second cycle is pipelined. In the pipelined cycle, the 82370 will start decoding the address and bus cycle signals one bus state earlier than in a non-pipelined cycle.

The READY# input signal is sampled by the 80376 host processor to determine the completion of a bus cycle. This occurs during the end of every T2, T2i and T2P state. Normally, the output of the 82370 Wait State Generator, READYO#, is directly connected to the READY# input of the 80376 host processor and the 82370. In such case, READYO# and READY# will be identical (see Wait State Generator).



NOTE:
ADAV—Internal Address Available

Figure 2-5. Master Mode State Diagram

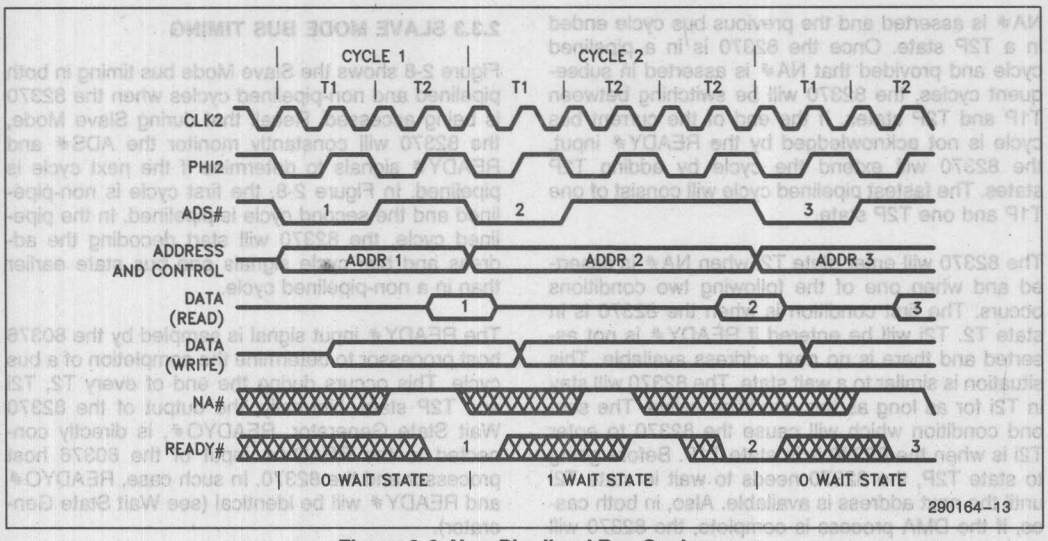


Figure 2-6. Non-Pipelined Bus Cycles

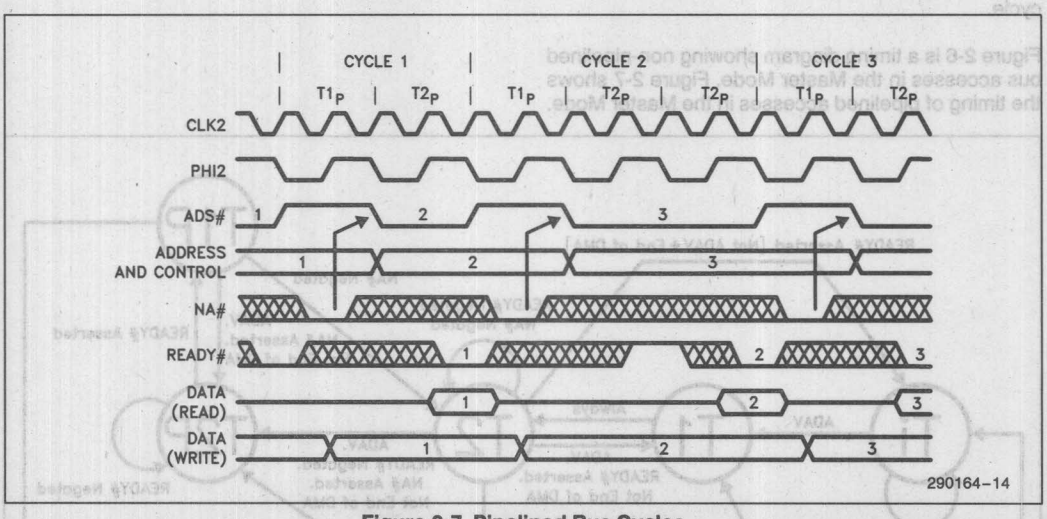
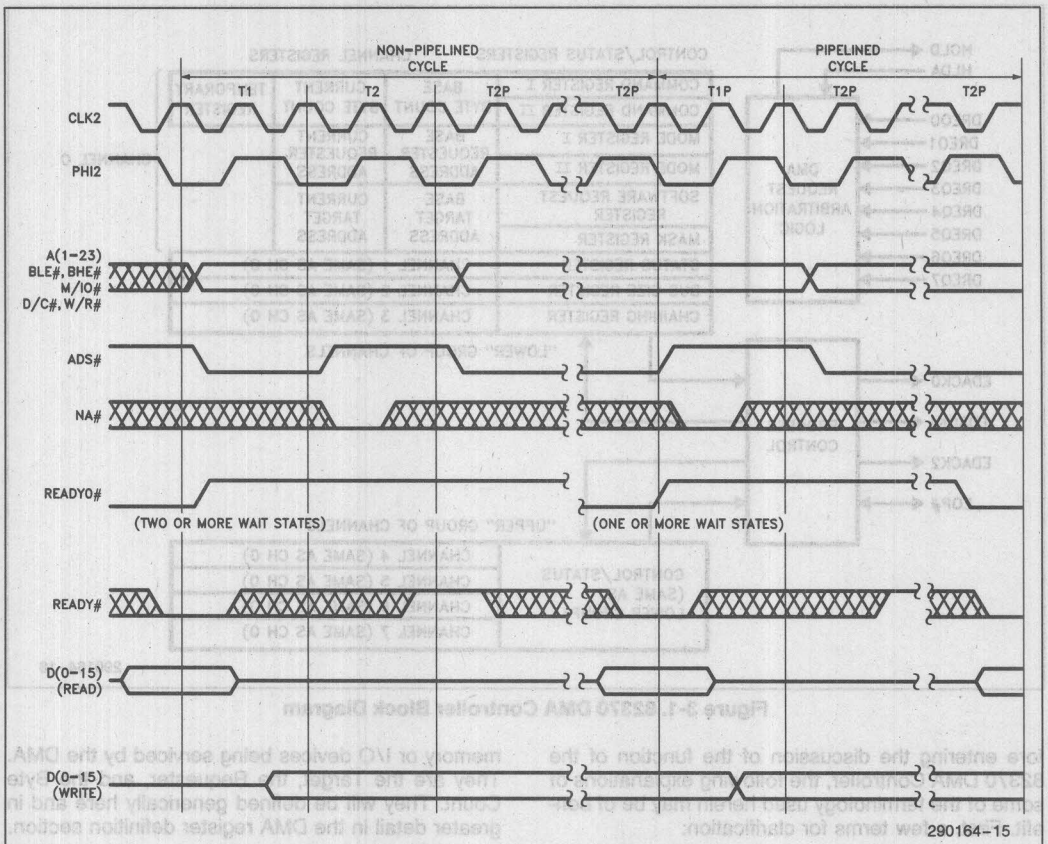


Figure 2-7. Pipelined Bus Cycles



NOTE:
NA# is shown here only for timing reference. It is not sampled by the 82370 during Slave Mode.
When the 82370 registers are accessed, it will take one or more wait states in pipelined and two or more wait states in non-pipelined cycle to complete the internal access.

Figure 2-8. Slave Read/Write Timing

3.0 DMA CONTROLLER

The 82370 DMA Controller is capable of transferring data between any combination of memory and/or I/O, with any combination of data path widths. The 82370 DMA Controller can be programmed to accommodate 8- or 16-bit devices. With its 16-bit external data path, it can transfer data in units of byte or a word. Bus bandwidth is optimized through the use of an internal temporary register which can disassemble or assemble data to or from either an aligned or non-aligned destination or source. Figure 3-1 is a block diagram of the 82370 DMA Controller.

The 82370 has eight channels of DMA. Each channel operates independently of the others. Within the operation of the individual channels, there are many different modes of data transfer available. Many of the operating modes can be intermixed to provide a very versatile DMA controller.

3.1 Functional Description

In describing the operation of the 82370's DMA Controller, close attention to terminology is required. Be-

9

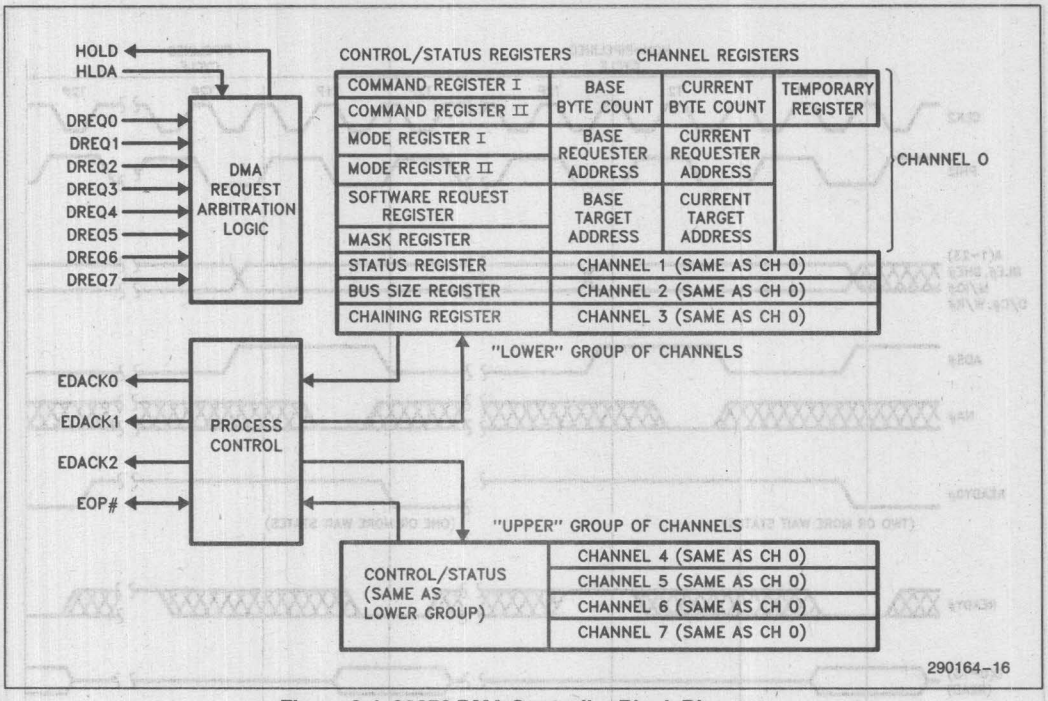


Figure 3-1. 82370 DMA Controller Block Diagram

fore entering the discussion of the function of the 82370 DMA Controller, the following explanations of some of the terminology used herein may be of benefit. First, a few terms for clarification:

DMA PROCESS—A DMA process is the execution of a programmed DMA task from beginning to end. Each DMA process requires intitial programming by the host 80376 microprocessor.

BUFFER—A contiguous block of data.

BUFFER TRANSFER—The action required by the DMA to transfer an entire buffer.

DATA TRANSFER—The DMA action in which a group of bytes or words are moved between devices by the DMA Controller. A data transfer operation may involve movement of one or many bytes.

BUS CYCLE—Access by the DMA to a single byte or word.

Each DMA channel consists of three major components. These components are identified by the contents of programmable registers which define the memory or I/O devices being serviced by the DMA. They are the Target, the Requester, and the Byte Count. They will be defined generically here and in greater detail in the DMA register definition section.

The Requester is the device which requires service by the 82370 DMA Controller, and makes the request for service. All of the control signals which the DMA monitors or generates for specific channels are logically related to the Requester. Only the Requester is considered capable of initiating or terminating a DMA process.

The Target is the device with which the Requester wishes to communicate. As far as the DMA process is concerned, the Target is a slave which is incapable of control over the process.

The direction of data transfer can be either from Requester to Target or from Target to Requester; i.e. each can be either a source or a destination.

The Requester and Target may each be either I/O or memory. Each has an address associated with it that can be incremented, decremented, or held constant. The addresses are stored in the Requester

Address Registers and Target Address Registers, respectively. These registers have two parts: one which contains the current address being used in the DMA process (Current Address Register), and one which holds the programmed base address (Base Address Register). The contents of the Base Registers are never changed by the 82370 DMA Controller. The Current Registers are incremented or decremented according to the progress of the DMA process.

The Byte Count is the component of the DMA process which dictates the amount of data which must be transferred. Current and Base Byte Count Registers are provided. The Current Byte Count Register is decremented once for each byte transferred by the DMA process. When the register is decremented past zero, the Byte Count is considered 'expired' and the process is terminated or restarted, depending on the mode of operation of the channel. The point at which the Byte Count expires is called 'Terminal Count' and several status signals are dependent on this event.

Each channel of the 82370 DMA Controller also contains a 32-bit Temporary Register for use in assembling and disassembling non-aligned data. The operation of this register is transparent to the user, although the contents of it may affect the timing of some DMA handshake sequences. Since there is data storage available for each channel, the DMA Controller can be interrupted without loss of data.

To avoid unexpected results, care should be taken in programming the byte count correctly when assembing and disassembling non-aligned data. For example:

Words to Bytes:
Transferring two words to bytes, but setting the byte count to three, will result in three bytes transferred and the final byte flushed.

Bytes to Words:
Transferring six bytes to three words, but setting the byte count to five, will result in the sixth byte transferred being undefined.

The 82370 DMA Controller is a slave on the bus until a request for DMA service is received via either a software request command or a hardware request signal. The host processor may access any of the control/status or channel registers at any time the 82370 is a bus slave. Figure 3-2 shows the flow of operations that the DMA Controller performs.

At the time a DMA service request is received, the DMA Controller issues a bus hold request to the host processor. The 82370 becomes the bus master when the host relinquishes the bus by asserting a hold acknowledge signal. The channel to be serviced will be the one with the highest priority at the time the DMA Controller becomes the bus master. The DMA Controller will remain in control of the bus until the hold acknowledge signal is removed, or until the current DMA transfer is complete.

While the 82370 DMA Controller has control of the bus, it will perform the required data transfer(s). The type of transfer, source and destination addresses, and amount of data to transfer are programmed in the control registers of the DMA channel which received the request for service.

At completion of the DMA process, the 82370 will remove the bus hold request. At this time the 82370 becomes a slave again, and the host returns to being a master. If there are other DMA channels with requests pending, the controller will again assert the hold request signal and restart the bus arbitration and switching process.

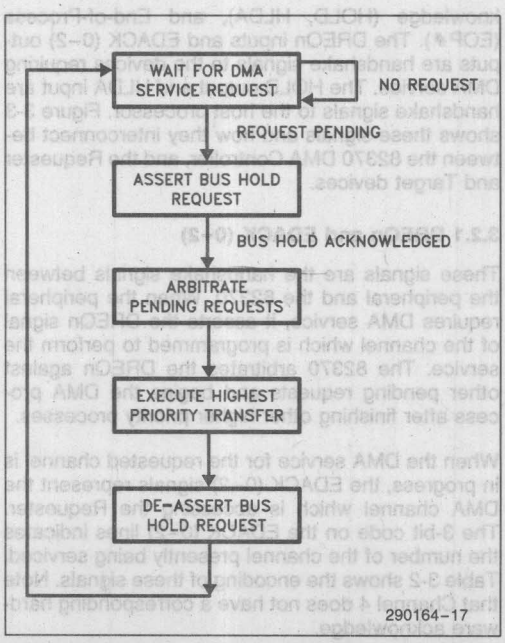


Figure 3-2. Flow of DMA Controller Operation

3.2 Interface Signals

There are fourteen control signals dedicated to the DMA process. They include eight DMA Channel Requests (DREQn), three Encoded DMA Acknowledge signals (EDACKn), Processor Hold and Hold Ac-

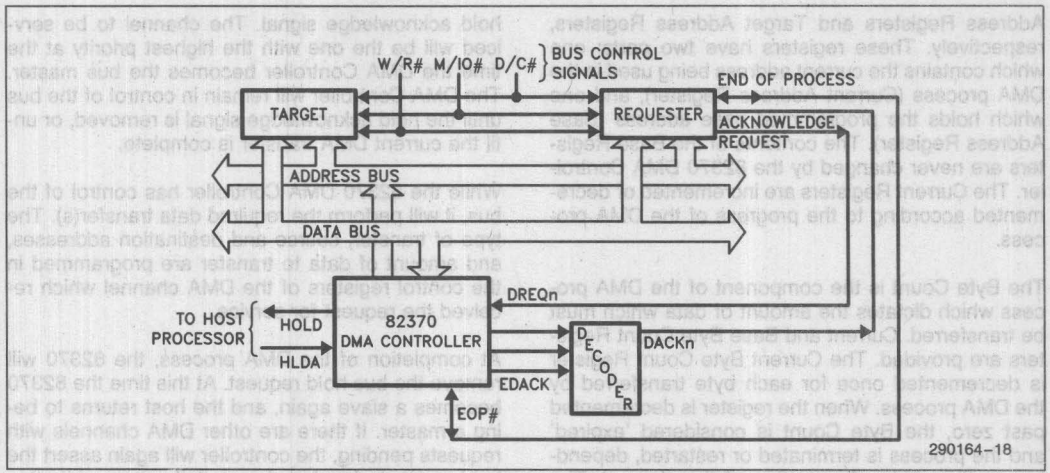


Figure 3-3. Requester, Target and DMA Controller Interconnection

knowledge (HOLD, HLDA), and End-of-Process (EOP#). The DREQn inputs and EDACK (0–2) outputs are handshake signals to the devices requiring DMA service. The HOLD output and HLDA input are handshake signals to the host processor. Figure 3-3 shows these signals and how they interconnect between the 82370 DMA Controller, and the Requester and Target devices.

3.2.1 DREQn and EDACK (0–2)

These signals are the handshake signals between the peripheral and the 82370. When the peripheral requires DMA service, it asserts the DREQn signal of the channel which is programmed to perform the service. The 82370 arbitrates the DREQn against other pending requests and begins the DMA process after finishing other higher priority processes.

When the DMA service for the requested channel is in progress, the EDACK (0–2) signals represent the DMA channel which is accessing the Requester. The 3-bit code on the EDACK (0–2) lines indicates the number of the channel presently being serviced. Table 3-2 shows the encoding of these signals. Note that Channel 4 does not have a corresponding hardware acknowledge.

The DMA acknowledge (EDACK) signals indicate the active channel only during DMA accesses to the Requester. During accesses to the Target, EDACK (0–2) has the idle code (100). EDACK (0–2) can thus be used to select a Requester device during a transfer.

DREQn can be programmed as either an Asynchronous or Synchronous input. See section 3.4.1 for details on synchronous versus asynchronous operation of these pins.

Table 3-2. EDACK Encoding During a DMA Transfer

EDACK2	EDACK1	EDACK0	Active Channel
0	0	0	0
0	0	1	1
0	1	0	2
0	1	1	3
1	0	0	Target Access
1	0	1	5
1	1	0	6
1	1	1	7

The EDACKn signals are always active. They either indicate 'no acknowledge' or they indicate a bus access to the requester. The acknowledge code is either 100, for an idle DMA or during a DMA access to the Target, or 'n' during a Requester access, where n is the binary value representing the channel. A simple 3-line to 8-line decoder can be used to provide discrete acknowledge signals for the peripherals.

3.2.2 HOLD AND HLDA

The Hold Request (HOLD) and Hold Acknowledge (HLDA) signals are the handshake signals between the DMA Controller and the host processor. HOLD is an output from the 82370 and HLDA is an input. HOLD is asserted by the DMA Controller when there is a pending DMA request, thus requesting the processor to give up control of the bus so the DMA process can take place. The 80376 responds by asserting HLDA when it is ready to relinquish control of the bus.

The 82370 will begin operations on the bus one clock cycle after the HLDA signal goes active. For this reason, other devices on the bus should be in the slave mode when HLDA is active.

HOLD and HLDA should not be used to gate or select peripherals requesting DMA service. This is because of the use of DMA-like operations by the DRAM Refresh Controller. The Refresh Controller is arbitrated with the DMA Controller for control of the bus, and refresh cycles have the highest priority. A refresh cycle will take place between DMA cycles without relinquishing bus control. See section 3.4.3 for a more detailed discussion of the interaction between the DMA Controller and the DRAM Refresh Controller.

3.2.3 EOP#

EOP# is a bi-directional signal used to indicate the end of a DMA process. The 82370 activates this as an output during the T2 states of the last Requester bus cycle for which a channel is programmed to execute. The Requester should respond by either withdrawing its DMA request, or interrupting the host processor to indicate that the channel needs to be programmed with a new buffer. As an input, this signal is used to tell the DMA Controller that the peripheral being serviced does not require any more data to be transferred. This indicates that the current buffer is to be terminated.

EOP# can be programmed as either an Asynchronous or a Synchronous input. See section 3.4.1 for details on synchronous versus asynchronous operation of this pin.

3.3 Modes of Operation

The 82370 DMA Controller has many independent operating functions. When designing peripheral interfaces for the 82370 DMA Controller, all of the functions or modes must be considered. All of the channels are independent of each other (except in priority of operation) and can operate in any of the modes. Many of the operating modes, though independently programmable, affect the operation of other modes. Because of the large number of combinations possible, each programmable mode is discussed here with its affects on the operation of other modes. The entire list of possible combinations will not be presented.

Table 3-1 shows the categories of DMA features available in the 82370. Each of the five major categories is independent of the others. The sub-categories are the available modes within the major function or mode category. The following sections explain each mode or function and its relation to other features.

Table 3-1. DMA Operating Modes

I. TARGET/REQUESTER DEFINITION
a. Data Transfer Direction
b. Device Type
II. BUFFER PROCESSES
a. Single Buffer Process
b. Buffer Auto-Initialize Process
c. Buffer Chaining Process
III. DATA TRANSFER/HANDSHAKE MODES
a. Single Transfer Mode
b. Demand Transfer Mode
c. Block Transfer Mode
d. Cascade Mode
IV. PRIORITY ARBITRATION
a. Fixed
b. Rotating
c. Programmable Fixed
V. BUS OPERATION
a. Fly-By (Single-Cycle)/Two-Cycle
b. Data Path Width
c. Read, Write, or Verify Cycles

3.3.1 TARGET/REQUESTER DEFINITION

All DMA transfers involve three devices: the DMA Controller, the Requester, and the Target. Since the devices to be accessed by the DMA Controller vary widely, the operating characteristics of the DMA Controller must be tailored to the Requester and Target devices.

The Requester can be defined as either the source or the destination of the data to be transferred. This is done by specifying a Write or a Read transfer, respectively. In a Read transfer, the Target is the data source and the Requester is the destination for the data. In a Write transfer, the Requester is the source and the Target is the destination.

The Requester and Target addresses can each be independently programmed to be incremented, decremented, or held constant. As an example, the 82370 is capable of reversing a string of data by having the Requester address increment and the Target address decrement in a memory-to-memory transfer.

3.3.2 BUFFER TRANSFER PROCESSES

The 82370 DMA Controller allows three programmable Buffer Transfer Processes. These processes define the logical way in which a buffer of data is accessed by the DMA.

The three Buffer Transfer Processes include the Single Buffer Process, the Buffer Auto-Initialize Process, and the Buffer Chaining Process. These processes require special programming considerations. See the DMA Programming section for more details on setting up the Buffer Transfer Processes.

Single Buffer Process

The Single Buffer Process allows the DMA channel to transfer only one buffer of data. When the buffer has been completely transferred (Current Byte Count decremented past zero or EOP# input active), the DMA process ends and the channel becomes idle. In order for that channel to be used again, it must be reprogrammed.

The Single Buffer Process is usually used when the amount of data to be transferred is known exactly, and it is also known that there is not likely to be any data to follow before the operating system can reprogram the channel.

Buffer Auto-Initialize Process

The Buffer Auto-Initialize Process allows multiple groups of data to be transferred to or from a single buffer. This process does not require reprogramming. The Current Registers are automatically reprogrammed from the Base Registers when the current process is terminated, either by an expired Byte Count or by an external EOP# signal. The data transferred will always be between the same Target and Requester.

The auto-initialization/process-execution cycle is repeated until the channel is either disabled or re-programmed.

Buffer Chaining Process

The Buffer Chaining Process is useful for transferring large quantities of data into non-contiguous buffer areas. In this process, a single channel is used to process data from several buffers, while having to program the channel only once. Each new buffer is programmed in a pipelined operation that provides the new buffer information while the old buffer is being processed. The chain is created by loading new buffer information while the 82370 DMA Controller is processing the Current Buffer. When the Current Buffer expires, the 82370 DMA Controller automatically restarts the channel using the new buffer information.

Loading the new buffer information is done by an interrupt routine which is requested by the 82370. Interrupt Request 1 (IRQ1) is tied internally to the 82370 DMA Controller for this purpose. IRQ1 is generated by the 82370 when the new buffer information is loaded into the channel's Current Registers, leaving the Base Registers 'empty'. The interrupt service routine loads new buffer information into the Base Registers. The host processor is required to load the information for another buffer before the current Byte Count expires. The process repeats until the host programs the channel back to single buffer operation, or until the channel runs out of buffers.

The channel runs out of buffers when the Current Buffer expires and the Base Registers have not yet been loaded with new buffer information. When this occurs, the channel must be reprogrammed.

If an external EOP# is encountered while executing a Buffer Chaining Process, the current buffer is considered expired and the new buffer information is loaded into the Current Registers. If the Base Registers are 'empty', the chain is terminated.

The channel uses the Base Target Address Register as an indicator of whether or not the Base Registers are full. When the most significant byte of the Base Target Register is loaded, the channel considers all of the Base Registers loaded, and removes the interrupt request. This requires that the other Base Registers (Base Requester Address, Base Byte Count) must be loaded before the Base Target Address Register. The reason for implementing the reloading process this way is that, for most applications, the Byte Count and the Requester will not change from one buffer to the next, and therefore do not need to be reprogrammed. The details of programming the channel for the Buffer Chaining Process can be found in the section on DMA programming.

3.3.3 DATA TRANSFER MODES

Three Data Transfer modes are available in the 82370 DMA Controller. They are the Single Transfer, Block Transfer, and Demand Transfer Modes. These transfer modes can be used in conjunction with any one of three Buffer Transfer modes: Single Buffer, Auto-Initialized Buffer and Buffer Chaining. Any Data Transfer Mode can be used under any of the Buffer Transfer Modes. These modes are independently available for all DMA channels.

Different devices being serviced by the DMA Controller require different handshaking sequences for data transfers to take place. Three handshaking modes are available on the 82370, giving the designer the opportunity to use the DMA Controller as efficiently as possible. The speed at which data can

be presented or read by a device can affect the way a DMA Controller uses the host's bus, thereby affecting not only data throughput during the DMA process, but also affecting the host's performance by limiting its access to the bus.

Single Transfer Mode

In the Single Transfer Mode, one data transfer to or from the Requester is performed by the DMA Controller at a time. The DREQn input is arbitrated and the HOLD/HLDA sequence is executed for each transfer. Transfers continue in this manner until the Byte Count expires, or until EOP# is sampled active. If the DREQn input is held active continuously, the entire DREQ-HOLD-HLDA-DACK sequence is repeated over and over until the programmed number of bytes has been transferred. Bus control is released to the host between each transfer. Figure 3-4 shows the logical flow of events which make up a buffer transfer using the Single Transfer Mode. Refer to section 3.4 for an explanation of the bus control arbitration procedure.

The Single Transfer Mode is used for devices which require complete handshake cycles with each data access. Data is transferred to or from the Requester only when the Requester is ready to perform the transfer. Each transfer requires the entire DREQ-HOLD-HLDA-DACK handshake cycle. Figure 3-5 shows the timing of the Single Transfer Mode cycle.

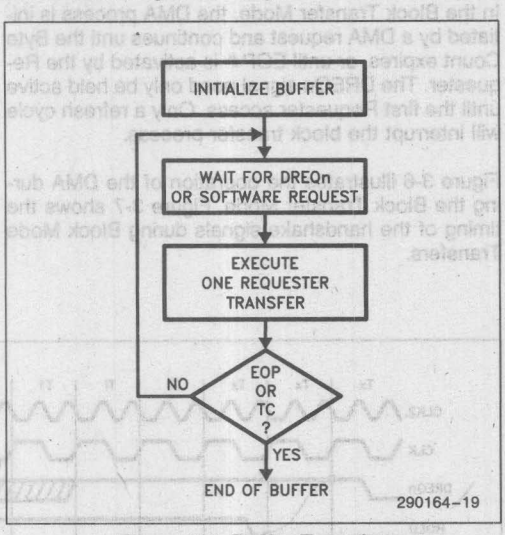
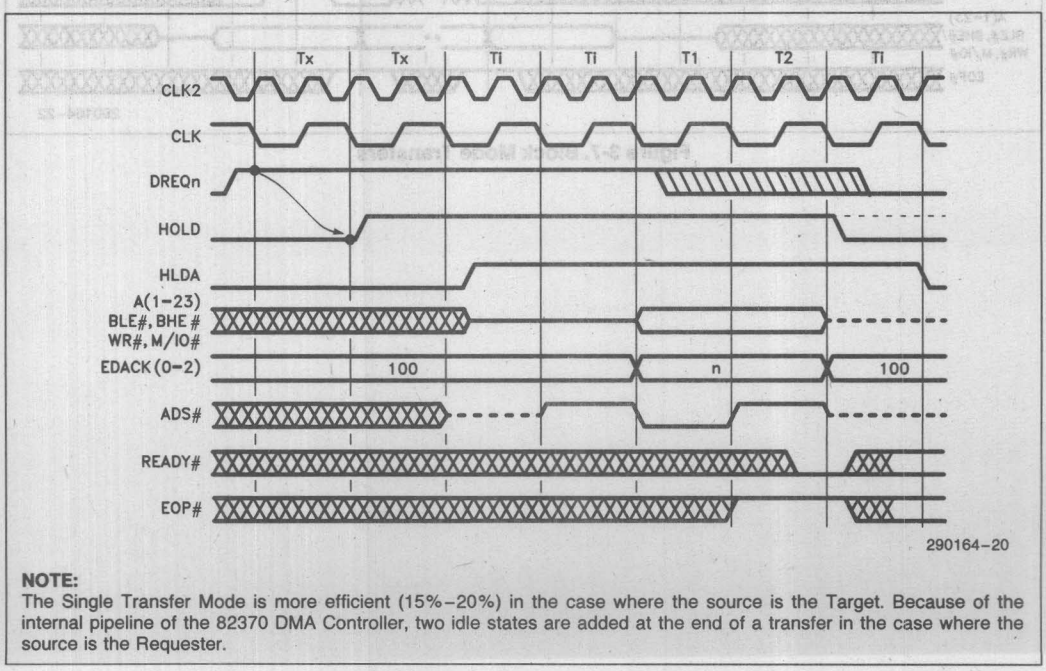


Figure 3-4. Buffer Transfer in Single Transfer Mode



NOTE:
The Single Transfer Mode is more efficient (15%–20%) in the case where the source is the Target. Because of the internal pipeline of the 82370 DMA Controller, two idle states are added at the end of a transfer in the case where the source is the Requester.

Figure 3-5. DMA Single Transfer Mode

9

Block Transfer Mode

In the Block Transfer Mode, the DMA process is initiated by a DMA request and continues unti the Byte Count expires, or until EOP# is activated by the Requester. The DREQn signal need only be held active until the first Requester access. Only a refresh cycle will interrupt the block transfer process.

Figure 3-6 illustrates the operation of the DMA during the Block Transfer Mode. Figure 3-7 shows the timing of the handshake signals during Block Mode Transfers.

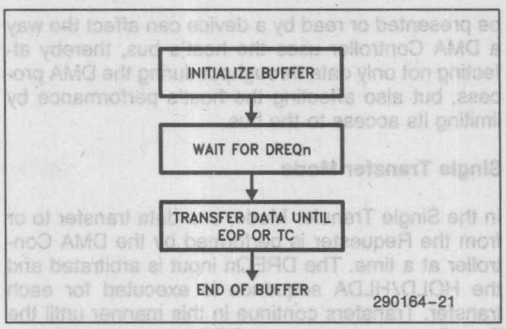


Figure 3-6. Buffer Transfer in Block Transfer Mode

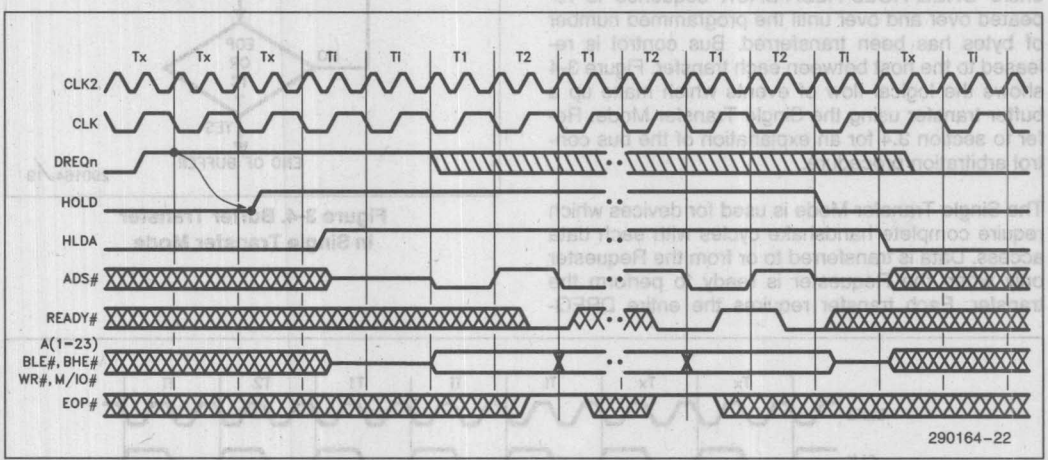


Figure 3-7. Block Mode Transfers

Demand Transfer Mode

The Demand Transfer Mode provides the most flexible handshaking procedures during the DMA process. A Demand Transfer is initiated by a DMA request. The process continues until the Byte Count expires, or an external EOP# is encountered. If the device being serviced (Requester) desires, it can interrupt the DMA process by de-activating the DREQn line. Action is taken on the condition of DREQn during Requester accesses only. The access during which DREQn is sampled inactive is the last Requester access which will be performed during the current transfer. Figure 3-8 shows the flow of events during the transfer of a buffer in the Demand Mode.

When the DREQn line goes inactive, the DMA Controller will complete the current transfer, including any necessary accesses to the Target, and relinquish control of the bus to the host. The current process information is saved (byte count, Requester and Target addresses, and Temporary Register).

The Requester can restart the transfer process by reasserting DREQn. The 82370 will arbitrate the request with other pending requests and begin the process where it left off. Figure 3-9 shows the timing of handshake signals during Demand Transfer Mode operation.

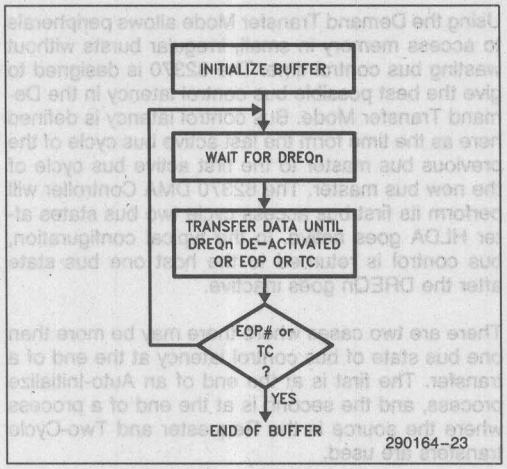


Figure 3-8. Buffer Transfer in Demand Transfer Mode

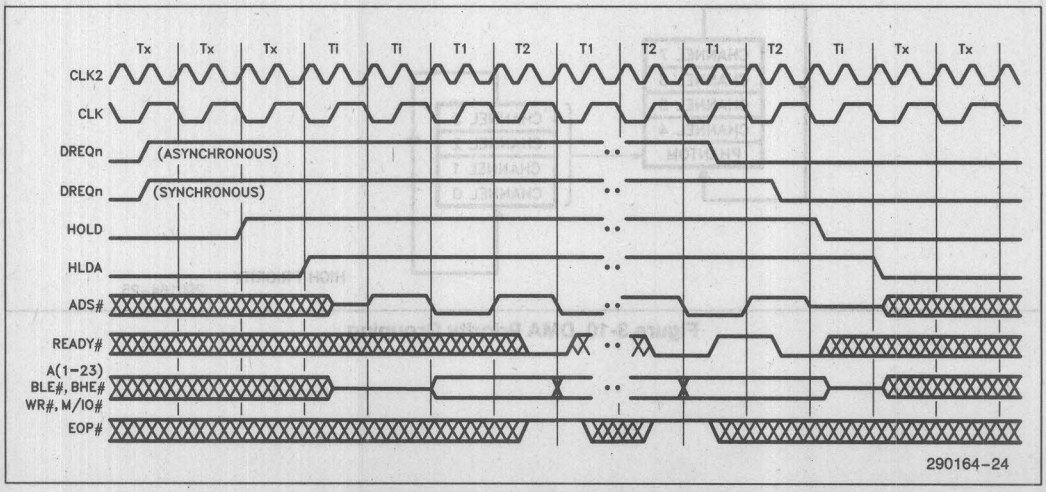


Figure 3-9. Demand Mode Transfers

Using the Demand Transfer Mode allows peripherals to access memory in small, irregular bursts without wasting bus control time. The 82370 is designed to give the best possible bus control latency in the Demand Transfer Mode. Bus control latency is defined here as the time form the last active bus cycle of the previous bus master to the first active bus cycle of the new bus master. The 82370 DMA Controller will perform its first bus access cycle two bus states after HLDA goes active. In the typical configuration, bus control is returned to the host one bus state after the DREQn goes inactive.

There are two cases where there may be more than one bus state of bus control latency at the end of a transfer. The first is at the end of an Auto-Initialize process, and the second is at the end of a process where the source is the Requester and Two-Cycle transfers are used.

When a Buffer Auto-Initialize Porcess is complete, the 82370 requires seven bus states to reload the Current Registers from the Base Registers of the Auto-Initialized channel. The reloading is done while the 82370 is still the bus master so that it is prepared to service the channel immediately after relinquishing the bus, if necessary.

In the case where the Requester is the source, and Two-Cycle transfers are being used, there are two extra idle states at the end of the transfer process. This occurs due to the housekeeping in the DMA's internal pipeline. These two idle states are present only after the very last Requester access, before the DMA Controller de-activates the HOLD signal.

3.3.4 CHANNEL PRIORITY ARBITRATION

DMA channel priority can be programmed into one of two arbitration methods: Fixed or Rotating. The four lower DMA channels and the four upper DMA channels operate as if they were two separate DMA controllers operating in cascade. The lower group of four channels (0–3) is always prioritized between channels 7 and 4 of the upper group of channels (4–7). Figure 3-10 shows a pictorial representation of the priority grouping.

The priority can thus be set up as rotating for one group of channels and fixed for the other, or any other combination. While in Fixed Priority, the programmer can also specify which channel has the lowest priority.

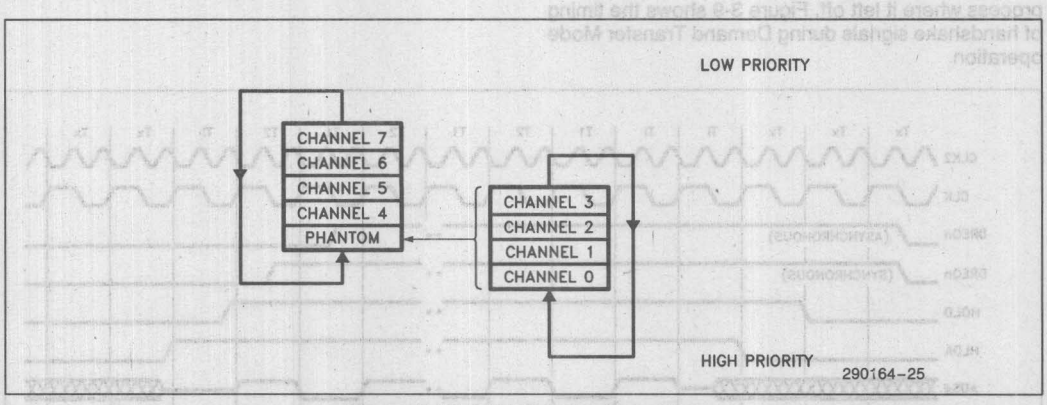


Figure 3-10. DMA Priority Grouping

The 82370 DMA Controller defaults to Fixed Priority. Channel 0 has the highest priority, then 1, 2, 3, 4, 5, 6, 7. Channel 7 has the lowest priority. Any time the DMA Controller arbitrates DMA requests, the requesting channel with the highest priority will be serviced next.

Fixed Priority can be entered into at any time by a software command. The priority levels in effect after the mode switch are determined by the current setting of the Programmable Priority.

Programmable Priority is available for fixing the priority of the DMA channels within a group to levels other than the default. Through a software command, the channel to have the lowest priority in a group can be specified. Each of the two groups of four channels can have the priority fixed in this way. The other channels in the group will follow the natural Fixed Priority sequence. This mode affects only the priority levels while operating with Fixed Priority.

For example, if channel 2 is programmed to have the lowest priority in its group, channel 3 has the highest priority. In descending order, the other channels would have the following priority: (3,0,1,2),4,5,6,7 (channel 2 lowest, channel 3 highest). If the upper group were programmed to have channel 5 as the lowest priority channel, the priority would be (again, highest to lowest): 6,7, (3,0,1,2), 4,5. Figure 3-11 shows this example pictorially. The lower group is always prioritized as a fifth channel of the upper group (between channels 4 and 7).

The DMA Controller will only accept Programmable Priority commands while the addressed group is operating in Fixed Priority. Switching from Fixed to Rotating Priority preserves the current priority levels. Switching from Rotating to Fixed Priority returns the priority levels to those which were last programmed by use of Programmable Priority.

Rotating Priority allows the devices using DMA to share the system bus more evenly. An individual channel does not retain highest priority after being serviced, priority is passed to the next highest priority channel in the group. The channel which was most recently serviced inherits the lowest priority. This rotation occurs each time a channel is serviced. Figure 3-12 shows the sequence of events as priority is passed between channels. Note that the lower group rotates within the upper group, and that servicing a channel within the lower group causes rotation within the group as well as rotation of the upper group.

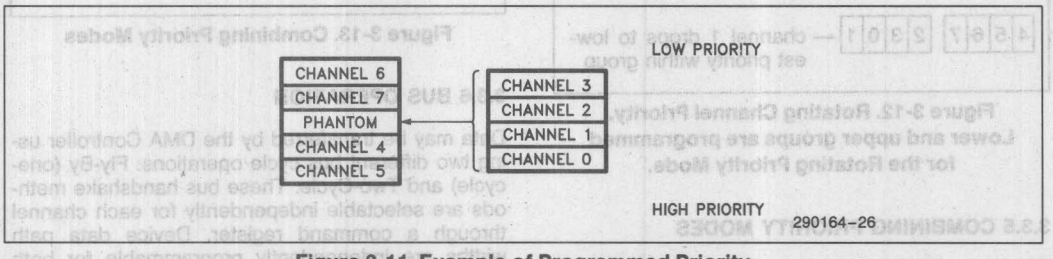


Figure 3-11. Example of Programmed Priority

9

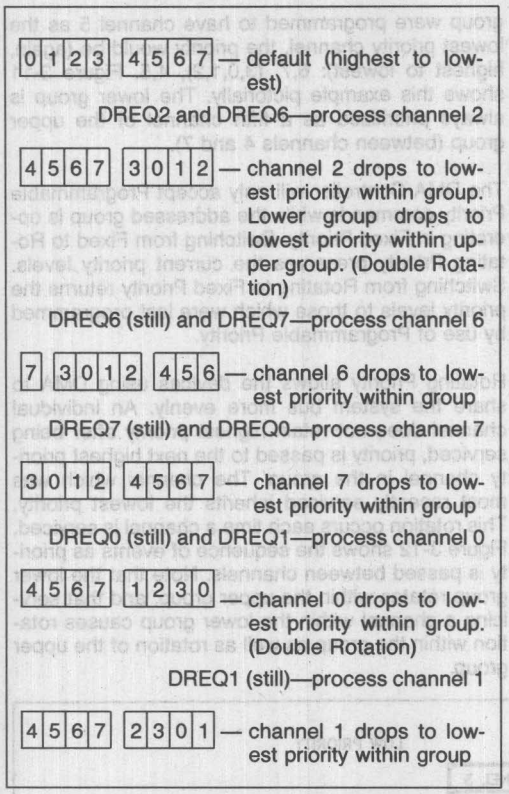


Figure 3-12. Rotating Channel Priority. Lower and upper groups are programmed for the Rotating Priority Mode.

3.3.5 COMBINING PRIORITY MODES

Since the DMA Controller operates as two four-channel controllers in cascade, the overall priority scheme of all eight channels can take on a variety of forms. There are four possible combinations of priority modes between the two groups of channels: Fixed Priority only (default), Fixed Priority upper group/Rotating Priority lower group, Rotating Priority upper group/Fixed Priority lower group, and Rotating Priority only. Figure 3-13 illustrates the operation of the two combined priority methods.

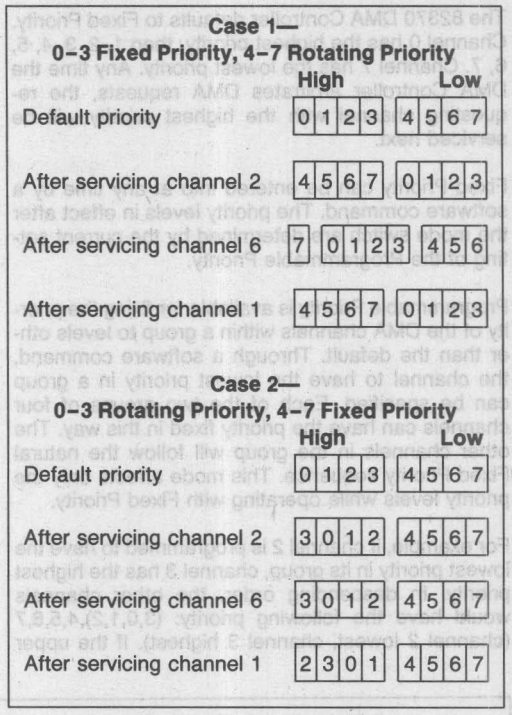


Figure 3-13. Combining Priority Modes

3.3.6 BUS OPERATION

Data may be transferred by the DMA Controller using two different bus cycle operations: Fly-By (one-cycle) and Two-Cycle. These bus handshake methods are selectable independently for each channel through a command register. Device data path widths are independently programmable for both Target and Requester. Also selectable through software is the direction of data transfer. All of these parameters affect the operation of the 82370 on a bus-cycle by bus-cycle basis.

3.3.6.1 Fly-By Transfers

The Fly-By Transfer Mode is the fastest and most efficient way to use the 82370 DMA Controller to transfer data. In this method of transfer, the data is written to the destination device at the same time it is read from the source. Only one bus cycle is used to accomplish the transfer.

In the Fly-By Mode, the DMA acknowledge signal is used to select the Requester. The DMA Controller simultaneously places the address of the Target on the address bus. The state of M/IO# and W/R# during the Fly-By transfer cycle indicate the type of Target and whether the Target is being written to or read from. The Target's Bus Size is used as an incrementer for the Byte Count. The Requester address registers are ignored during Fly-By transfers.

Note that memory-to-memory transfers cannot be done using the Fly-By Mode. Only one memory of I/O address is generated by the DMA Controller at a time during Fly-By transfers. Only one of the devices being accessed can be selected by an address. Also, the Fly-By method of data transfer limits the hardware to accesses of devices with the same data bus width. The Temporary Registers are not affected in the Fly-By Mode.

Fly-By transfers also require that the data paths of the Target and Requester be directly connected. This requires that successive Fly-By access be to word boundaries, or that the Requester be capable of switching its connections to the data bus.

3.3.6.2. Two-Cycle Transfers

Two-Cycle transfers can also be performed by the 82370 DMA Controller. These transfers require at least two bus cycles to execute. The data being transferred is read into the DMA Controller's Temporary Register during the first bus cycle(s). The second bus cycle is used to write the data from the Temporary Register to the destination.

If the addresses of the data being transferred are not word aligned, the 82370 will recognize the situation and read and write the data in groups of bytes, placing them always at the proper destination. This process of collecting the desired bytes and putting them together is called "byte assembly". The reverse process (reading from aligned locations and writing to non-aligned locations) is called "byte disassembly".

The assembly/disassembly process takes place transparent to the software, but can only be done while using the Two-Cycle transfer method. The 82370 will always perform the assembly/disassembly process as necessary for the current data transfer. Any data path widths for either the Requester or Target can be used in the Two-Cycle Mode. This is very convenient for interfacing existing 8- and 16-bit peripherals to the 80376's 16-bit bus.

The 82370 DMA Controller always reads and write data within the word boundaries; i.e. if a word to be read is crossing a word boundary, the DMA Controller will perform two read operations, each reading one byte, to read the 16-bit word into the Temporary Register. Also, the 82370 DMA Controller always attempts to fill the Temporary Register from the source before writing any data to the destination. If the process is terminated before the Temporary Register is filled (TC or EOP#), the 82370 will write the partial data to the destination. If a process is temporarily suspended (such as when DREQn is deactivated during a demand transfer), the contents of a partially filled Temporary Register will be stored within the 82370 until the process is restarted.

For example, if the source is specified as an 8-bit device and the destination as a 32-bit device, there will be four reads as necessary from the 8-bit source to fill the Temporary Register. Then the 82370 will write the 32-bit contents to the destination in two cycles of 16-bit each. This cycle will repeat until the process is terminated or suspended.

With Two-Cycle transfers, the devices that the 82370 accesses can reside at any address within I/O or memory space. The device must be able to decode the byte-enables (BLE#, BHE#). Also, if the device cannot accept data in byte quantities, the programmer must take care not to allow the DMA Controller to access the device on any address other than the device boundary.

3.3.6.3 Data Path Width and Data Transfer Rate Considerations

The number of bus cycles used to transfer a single "word" of data is affected by whether the Two-Cycle or the Fly-By (Single-Cycle) transfer method is used.

The number of bus cycles used to transfer data directly affects the data transfer rate. Inefficient use of bus cycles will decrease the effective data transfer rate that can be obtained. Generally, the data transfer rate is halved by using Two-Cycle transfers instead of Fly-By transfers.

The choice of data path widths of both Target and Requester affects the data transfer rate also. During each bus cycle, the largest pieces of data possible should be transferred.

The data path width of the devices to be accessed must be programmed into the DMA controller. The 82370 defaults after reset to 8-bit-to-8-bit data transfers, but the Target and Requester can have different data path widths, independent of each other and independent of the other channels. Since this is a software programmable function, more discussion of the uses of this feature are found in the section on programming.

3.3.6.4 Read, Write and Verify Cycles

Three different bus cycles types may be used in a data transfer. They are the Read, Write and Verify cycles. These cycle types dictate the way in which the 82370 operates on the data to be transferred.

A Read Cycle transfers data from the Target to the Requester. A Write Cycle transfers data from the Requester to the target. In a Fly-By transfer, the address and bus status signals indicate the access (read of write) to the Target; the access to the Requester is assumed to be the opposite.

The Verify Cycle is used to perform a data read only. No write access is indicated or assumed in a Verify Cycle. The Verify Cycle is useful for validating block fill operations. An external comparator must be provided to do any comparisons on the data read.

3.4 Bus Arbitration and Handshaking

Figure 3-14 shows the flow of events in the DMA request arbitration process. The arbitration sequence starts when the Requester asserts a DREQn (or DMA service is requested by software). Figure 3-15 shows the timing of the sequence of events following a DMA request. This sequence is executed for each channel that is activated. The DREQn signal can be replaced by a software DMA channel request with no change in the sequence.

After the Requester asserts the service request, the 82370 will request control of the bus via the HOLD signal. The 82370 will always assert the HOLD signal one bus state after the service request is asserted. The 80376 responds by asserting the HLDA signal, thus releasing control of the bus to the 82370 DMA Controller.

Priority of pending DMA service requests is arbitrated during the first state after HLDA is asserted by the 80376. The next state will be the beginning of the first transfer access of the highest priority process.

When the 82370 DMA Controller is finished with its current bus activity, it returns control of the bus to the host processor. This is done by driving the HOLD signal inactive. The 82370 does not drive any address or data bus signals after HOLD goes low. It enters the Slave Mode until another DMA process is requested. The processor acknowledges that it has regained control of the bus by forcing the HLDA signal inactive. Note that the 82370's DMA Controller will not re-request control of the bus until the entire HOLD/HLDA handshake sequence is complete.

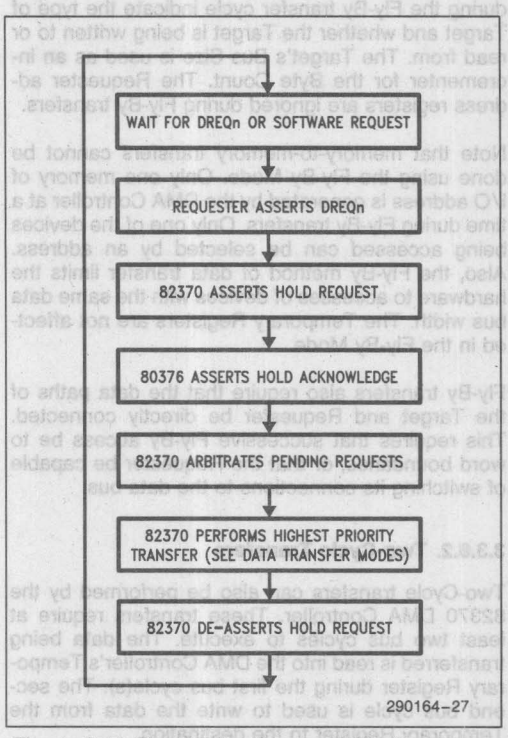
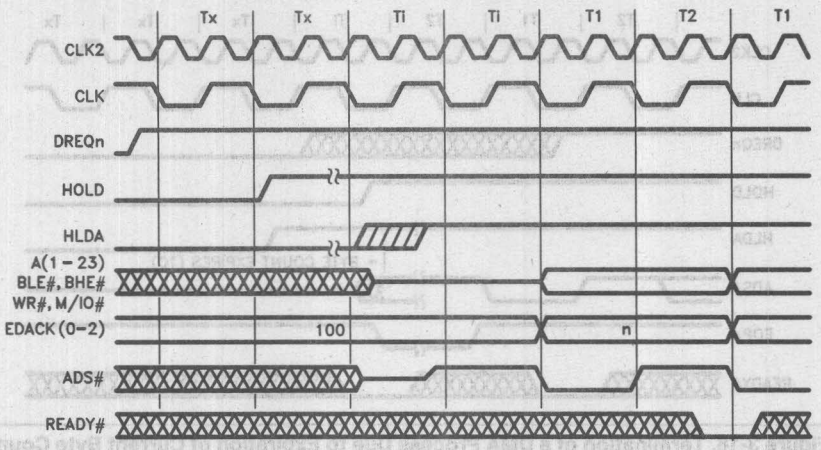


Figure 3-14. Bus Arbitration and DMA Sequence

The 82370 DMA Controller will terminate a current DMA process for one of three reasons: expired byte count, end-of-process command (EOP# activated) from a peripheral, or deactivated DMA request signal. In each case, the controller will de-assert HOLD immediately after completing the data transfer in progress. These three methods of process termination are illustrated in Figures 3-16, 3-19 and 3-18, respectively.

An expired byte count indicates that the current process is complete as programmed and the channel has no further transfers to process. The channel must be restarted according to the currently programmed Buffer Transfer Mode, or reprogrammed completely, including a new Buffer Transfer Mode.



NOTE:
290164-28
Channel priority resolution takes place during the bus state before HOLDA is asserted, allowing the DMA Controller to respond to HLDA without extra idle bus states.

Figure 3-15. Beginning of a DMA process

If the peripheral activates the EOP# signal, it is indicating that it will not accept or deliver any more data for the current buffer. The 82370 DMA Controller considers this as a completion of the channel's current process and interprets the condition the same way as if the byte count expired.

The action taken by the 82370 DMA Controller in response to a de-activated DREQn signal depends on the Data Transfer Mode of the channel. In the Demand Mode, data transfers will take place as long as the DREQn is active and the byte count has not expired. In the Block Mode, the controller will complete the entire block transfer without relinquishing the bus, even if DREQn goes inactive before the transfer is complete. In the Single Mode, the controller will execute single data transfers, relinquishing the bus between each transfer, as long as DREQn is active.

Normal termination of a DMA process due to expiration of the byte count (Terminal Count—TC) is shown if Figure 3-16. The condition of DREQn is ignored until after the process is terminated. If the channel is programmed to auto-initialize, HOLD will be held active for an additional seven clock cycles while the auto-initialization takes place.

Table 3-3 shows the DMA channel activity due to EOP# or Byte Count expiring (Terminal Count).

Table 3-3. DMA Channel Activity Due to Terminal Count or External EOP#

Buffer Process	Single or Chaining-Base Empty		Auto-Initialize		Chaining-Base Loaded	
EVENT						
Terminal Count	True	X	True	X	True	X
EOP#	X	0	X	0	X	0
RESULTS						
Current Registers			Load	Load	Load	Load
Channel Mask	Set	Set				
EOP# Output	0	X	0	X	1	X
Terminal Count Status	Set	Set	Set	Set		
Software Request	CLR	CLR	CLR	CLR		

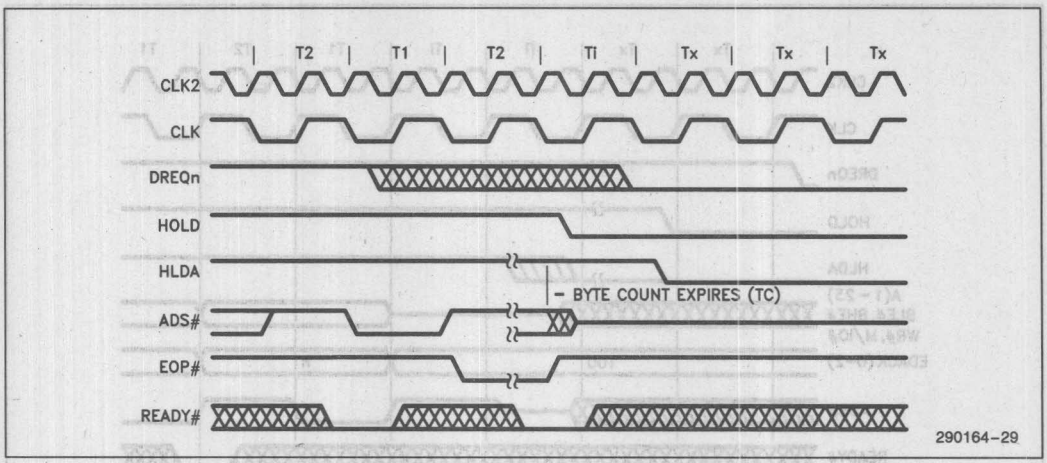


Figure 3-16. Termination of a DMA Process Due to Expiration of Current Byte Count

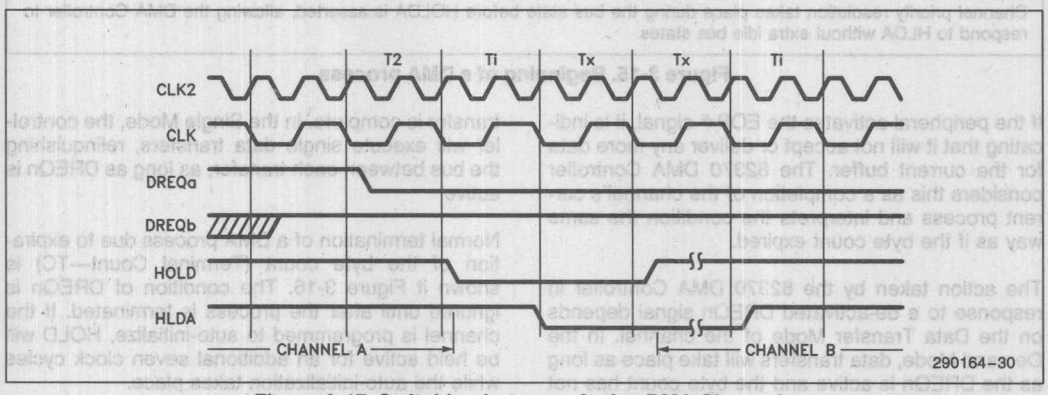


Figure 3-17. Switching between Active DMA Channels

The 82370 always relinquishes control of the bus between channel services. This allows the hardware designer the flexibility to externally arbitrate bus hold requests, if desired. If another DMA request is pending when a higher priority channel service is completed, the 82370 will relinquish the bus until the hold acknowledge is inactive. One bus state after the HLDA signal goes inactive, the 82370 will assert HOLD again. This is illustrated in Figure 3-17.

3.4.1 SYNCHRONOUS AND ASYNCHRONOUS SAMPLING OF DREQn AND EOP#

As an indicator that a DMA service is to be started, DREQn is always sampled asynchronous. It is sampled at the beginning of a bus state and acted upon at the end of the state. Figure 3-15 illustrates the start of a DMA process due to a DREQn input.

The DREQn and EOP# inputs can be programmed to be sampled either synchronously or asynchronously to signal the end of a transfer.

The synchronous mode affords the Requester one bus state of extra time to react to an access. This means the Requester can terminate a process on the current access, without losing any data. The asynchronous mode requires that the input signal be presented prior to the beginning of the last state of the Requester access.

The timing relationships of the DREQn and EOP# signals to the termination of a DMA transfer are shown in Figures 3-18 and 3-19. Figure 3-18 shows the termination of a DMA transfer due to inactive DREQn. Figure 3-19 shows the termination of a DMA process due to an active EOP# input.

In the Synchronous Mode, DREQn and EOP# are sampled at the end of the last state of every Requester data transfer cycle. If EOP# is active or DREQn is inactive at this time, the 82370 recognizes this access to the Requester as the last transfer. At this point, the 82370 completes the transfer in progress, if necessary, and returns bus control to the host.

In the asynchronous mode, the inputs are sampled at the beginning of every state of a Requester access. The 82370 waits until the end of the state to act on the input.

DREQn and EOP# are sampled at the latest possible time when the 82370 can determine if another transfer is required. In the Synchronous Mode, DREQn and EOP# are sampled on the trailing edge of the last bus state before another data access cycle begins. The Asynchronous Mode requires that the signals be valid one clock cycle earlier.

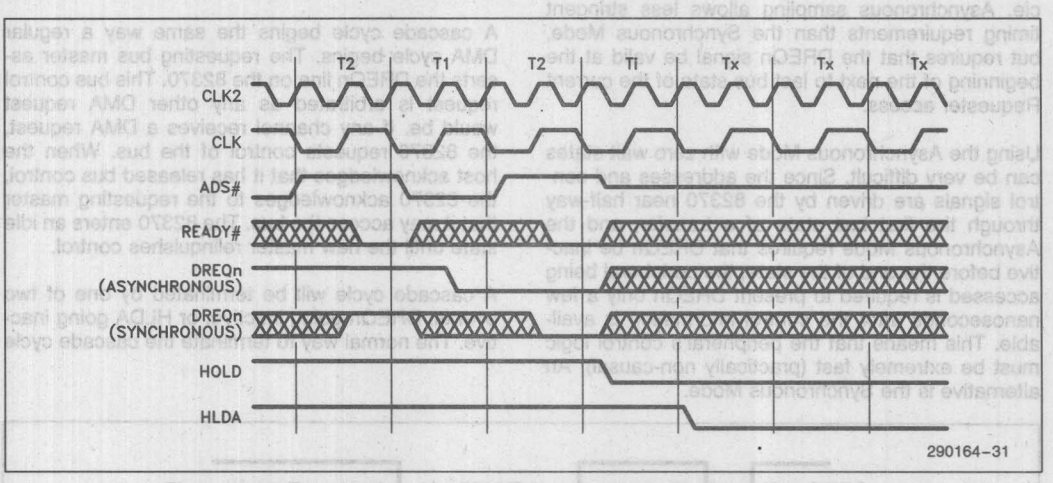


Figure 3-18. Termination of a DMA Process due to De-Asserting DREQn

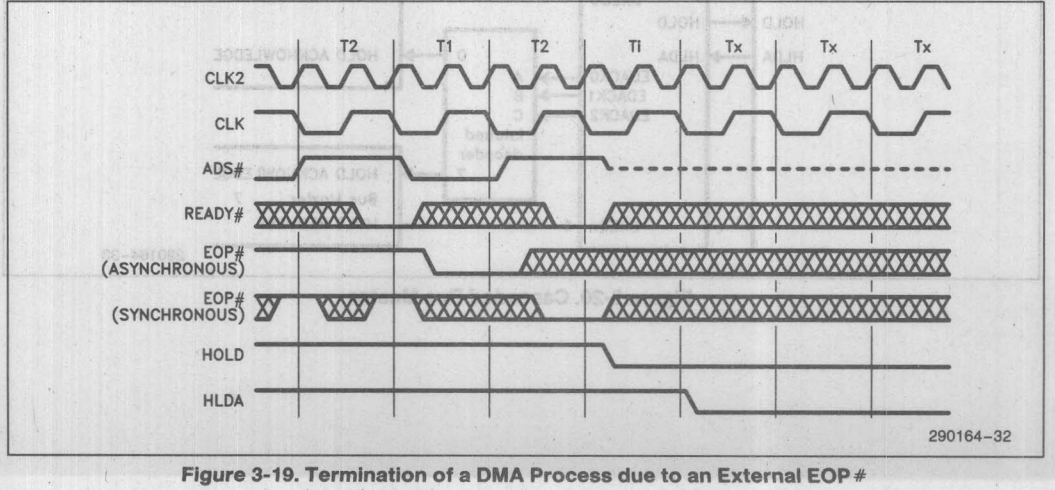


Figure 3-19. Termination of a DMA Process due to an External EOP#

While in the Pipeline Mode, if the NA# signal is sampled active during a transfer, the end of the state where NA# was sampled active is when the 82370 decides whether to commit to another transfer. The device must de-assert DREQn or assert EOP# before NA# is asserted, otherwise the 82370 will commit to another, possibly undesired, transfer.

Synchronous DREQn and EOP# sampling allows the peripheral to prevent the next transfer from occurring by de-activating DREQn or asserting EOP# during the current Requester access, before the 82370 DMA Controller commits itself to another transfer. The DMA Controller will not perform the next transfer if it has not already begun the bus cycle. Asynchronous sampling allows less stringent timing requirements than the Synchronous Mode, but requires that the DREQn signal be valid at the beginning of the next to last bus state of the current Requester access.

Using the Asynchronous Mode with zero wait states can be very difficult. Since the addresses and control signals are driven by the 82370 near half-way through the first bus state of a transfer, and the Asynchronous Mode requires that DREQn be inactive before the end of the state, the peripheral being accessed is required to present DREQn only a few nanoseconds after the control information is available. This means that the peripheral's control logic must be extremely fast (practically non-causal). An alternative is the Synchronous Mode.

3.4.2 ARBITRATION OF CASCADED MASTER REQUESTS

The Cascade Mode allows another DMA-type device to share the bus by arbitrating its bus accesses with the 82370's. Seven of the eight DMA channels (0–3 and 5–7) can be connected to a cascaded device. The cascaded device requests bus control through the DREQn line of the channel which is programmed to operate in Cascade Mode. Bus hold acknowledge is signalled to the cascaded device through the EDACK lines. When the EDACK lines are active with the code for the requested cascade channel, the bus is available to the cascaded master device.

A cascade cycle begins the same way a regular DMA cycle begins. The requesting bus master asserts the DREQn line on the 82370. This bus control request is arbitrated as any other DMA request would be. If any channel receives a DMA request, the 82370 requests control of the bus. When the host acknowledges that it has released bus control, the 82370 acknowledges to the requesting master that it may access the bus. The 82370 enters an idle state until the new master relinquishes control.

A cascade cycle will be terminated by one of two events: DREQn going inactive, or HLDA going inactive. The normal way to terminate the cascade cycle

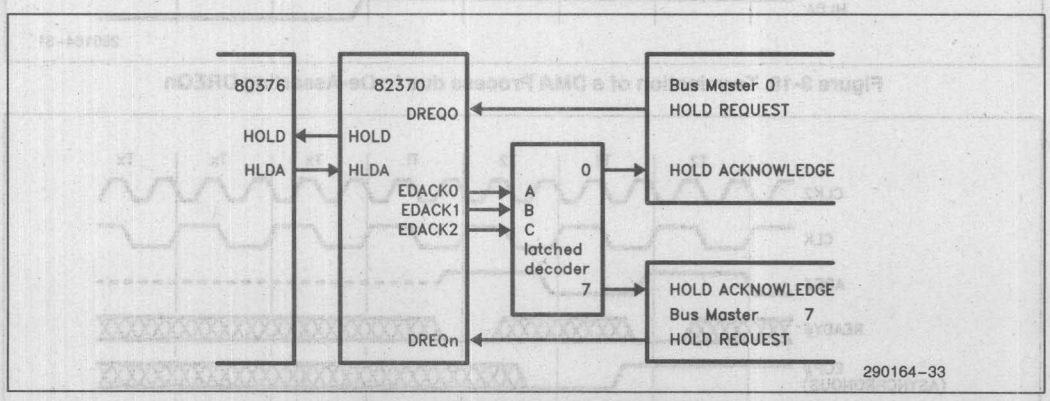


Figure 3-20. Cascaded Bus Master

is for the cascaded master to drop the DREQn signal. Figure 3-21 shows the two cascade cycle termination sequences.

The Refresh Controller may interrupt the cascaded master to perform a refresh cycle. If this occurs, the 82370 DMA Controller will de-assert the EDACK signal (hold acknowledge to cascaded master) and wait for the cascaded master to remove its hold request. When the 82370 regains bus control, it will perform the refresh cycle in its normal fashion. After the refresh cycle has been completed, and if the cascaded device has re-asserted its request, the 82370 will return control to the cascaded master which was interrupted.

The 82370 assumes that it is the only device monitoring the HLDA signal. If the system designer wishes to place other devices on the bus as bus masters, the HLDA from the processor must be intercepted before presenting it to the 82370. Using the Cascade capabililty of the 82370 DMA Controller offers a much better solution.

3.4.3 ARBITRATION OF REFRESH REQUESTS

The arbitration of refresh requests by the DRAM Refresh Controller is slightly different from normal DMA channel request arbitration. The 82370 DRAM Refresh Controller always has the highest priority of any DMA process. It also can interrupt a process in progress. Two types of processes in progress may be encountered: normal DMA, and bus master cascade.

In the event of a refresh request during a normal DMA process, the DMA Controller will complete the data transfer in progress and then execute the refresh cycle before continuing with the current DMA process. The priority of the interrupted process is not lost. If the data transfer cycle interrupted by the Refresh Controller is the last of a DMA process, the refresh cycle will always be executed before control of the bus is transferred back to the host.

When the Refresh Controller request occurs during a cascade cycle, the Refresh Controller must be assured that the cascaded master device has relinquished control of the bus before it can execute the refresh cycle. To do this, the DMA Controller drops the EDACK signal to the cascaded master and waits for the corresponding DREQn input to go inactive. By dropping the DREQn signal, the cascaded master relinquishes the bus. The Refresh Controller then performs the refresh cycle. Control of the bus is returned to the cascaded master if DREQn returns to an active state before the end of the refresh cycle, otherwise control is passed to the processor and the cascaded master loses its priority.

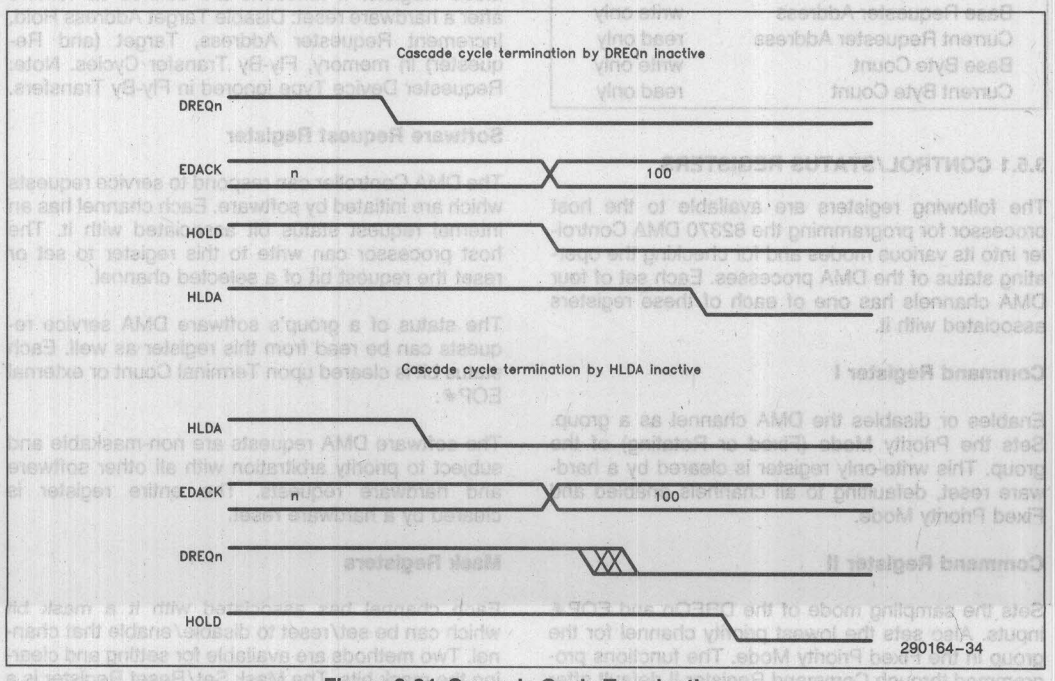


Figure 3-21. Cascade Cycle Termination

3.5 DMA Controller Register Overview

The 82370 DMA Controller contains 44 registers which are accessable to the host processor. Twenty-four of these registers contain the device addresses and data counts for the individual DMA channels (three per channel). The remaining registers are control and status registers for initiating and monitoring the operation of the 82370 DMA Controller. Table 3-4 lists the DMA Controller's registers and their accessability.

Table 3-4. DMA Controller Registers

Register Name	Access
Control/Status Registers—one each per group	
Command Register I	write only
Command Register II	write only
Mode Register I	write only
Mode Register II	write only
Software Request Register	read/write
Mask Set-Reset Register	write only
Mask Read-Write Register	read/write
Status Register	read only
Bus Size Register	write only
Chaining Register	read/write
Channel Registers—one each per channel	
Base Target Address	write only
Current Target Address	read only
Base Requester Address	write only
Current Requester Address	read only
Base Byte Count	write only
Current Byte Count	read only

3.5.1 CONTROL/STATUS REGISTERS

The following registers are available to the host processor for programming the 82370 DMA Controller into its various modes and for checking the operating status of the DMA processes. Each set of four DMA channels has one of each of these registers associated with it.

Command Register I

Enables or disables the DMA channel as a group. Sets the Priority Mode (Fixed or Rotating) of the group. This write-only register is cleared by a hardware reset, defaulting to all channels enabled and Fixed Priority Mode.

Command Register II

Sets the sampling mode of the DREQn and EOP# inputs. Also sets the lowest priority channel for the group in the Fixed Priority Mode. The functions programmed through Command Register II default after a hardware reset to: asynchronous DREQn and EOP#, and channels 3 and 7 lowest priority.

Mode Registers I

Mode Register I is identical in function to the Mode register of the 8237A. It programs the following functions for an individually selected channel:

Type of Transfer—read, write, verify
Auto-Initialize—enable or disable
Target Address Count—increment or decrement
Data Transfer Mode—demand, single, block, cascade

Mode Register I functions default to the following after reset: verify transfer, Auto-Initialize disabled, Increment Target address, Demand Mode.

Mode Register II

Programs the following functions for an individually selected channel:

Target Address Hold—enable or disable
Requester Address Count—increment or decrement
Requester Address Hold—enable or disable
Target Device Type—I/O or Memory
Requester Device Type—I/O or Memory
Transfer Cycles—Two-Cycle or Fly-By

Mode Register II functions are defined as follows after a hardware reset: Disable Target Address Hold, Increment Requester Address, Target (and Requester) in memory, Fly-By Transfer Cycles. Note: Requester Device Type ignored in Fly-By Transfers.

Software Request Register

The DMA Controller can respond to service requests which are initiated by software. Each channel has an internal request status bit associated with it. The host processor can write to this register to set or reset the request bit of a selected channel.

The status of a group's software DMA service requests can be read from this register as well. Each status bit is cleared upon Terminal Count or external EOP#.

The software DMA requests are non-maskable and subject to priority arbitration with all other software and hardware requests. The entire register is cleared by a hardware reset.

Mask Registers

Each channel has associated with it a mask bit which can be set/reset to disable/enable that channel. Two methods are available for setting and clearing the mask bits. The Mask Set/Reset Register is a

write-only register which allows the host to select an individual channel and either set or reset the mask bit for that channel only. The Mask Read/Write Register is available for reading the mask bit status and for writing mask bits in groups of four.

The mask bits of a group may be cleared in one step by executing the Clear Mask Command. See the DMA Programming section for details. A hardware reset sets all of the channel mask bits, disabling all channels.

Status Register

The Status register is a read-only register which contains the Terminal Count (TC) and Service Request status for a group. Four bits indicate the TC status and four bits indicate the hardware request status for the four channels in the group. The TC bits are set when the Byte Count expires, or when and external EOP# is asserted. These bits are cleared by reading from the Status Register. The Service Request bit for a channel indicates when there is a hardware DMA request (DREQn) asserted for that channel. When the request has been removed, the bit is cleared.

Bus Size Register

This write-only register is used to define the bus size of the Target and Requester of a selected channel. The bus sizes programmed will be used to dictate the sizes of the data paths accessed when the DMA channel is active. The values programmed into this register affect the operation of the Temporary Register. When 32-bit bus width is programmed, the 82370 DMA Controller will access the device twice through its 16-bit external Data Bus to perform a 32-bit data transfer. Any byte-assembly required to make the transfers using the specified data path widths will be done in the Temporary Register. The Bus Size register of the Target is used as an increment/decrement value for the Byte Counter and Target Address when in the Fly-By Mode. Upon reset, all channels default to 8-bit Targets and 8-bit Requesters.

Chaining Register

As a command or write register, the Chaining register is used to enable or disable the Chaining Mode for a selected channel. Chaining can either be disabled or enabled for an individual channel, independently of the Chaining Mode status of other channels. After a hardware reset, all channels default to Chaining disabled.

When read by the host, the Chaining Register provides the status of the Chaining Interrupt of each of the channels. These interrupt status bits are cleared when the new buffer information has been loaded.

3.5.2 CHANNEL REGISTERS

Each channel has three individually programmable registers necessary for the DMA process; they are the Base Byte Count, Base Target Address, and Base Requester Address registers. The 24-bit Base Byte Count register contains the number of bytes to be transferred by the channel. The 24-bit Base Target Address Register contains the beginning address (memory or I/O) of the Target device. The 24-bit Base Requester Address register contains the base address (memory or I/O) of the device which is to request DMA service.

Three more registers for each DMA channel exist within the DMA Controller which are directly related to the registers mentioned above. These registers contain the current status of the DMA process. They are the Current Byte Count register, the Current Target Address, and the Current Requester Address. It is these registers which are manipulated (incremented, decremented, or held constant) by the 82370 DMA Controller during the DMA process. The Current registers are loaded from the Base registers at the beginning of a DMA process.

The Base registers are loaded when the host processor writes to the respective channel register addresses. Depending on the mode in which the channel is operating, the Current registers are typically loaded in the same operation. Reading from the channel register addresses yields the contents of the corresponding Current register.

To maintain compatibility with software which accesses an 8237A, a Byte Pointer Flip-Flop is used to control access to the upper and lower bytes of some words of the Channel Registers. These words are accessed as byte pairs at single port addresses. The Byte Pointer Flip-Flop acts as a one-bit pointer which is toggled each time a qualifying Channel Register byte is accessed.

It always points to the next logical byte to be accessed of a pair of bytes.

The Channel registers are arranged as pairs of words, each pair with its own port address. Addressing the port with the Byte Pointer Flip-Flop reset accesses the least significant byte of the pair. The most significant byte is accessed when the Byte Pointer is set.

For compatibility with existing 8237A designs, there is one exception to the above statements about the Byte Pointer Flip-Flop. The third byte (bits 16-23) of the Target Address is accessed through its own port address. The Byte Pointer Flip-Flop is not affected by any accesses to this byte.

The upper eight bits of the Byte Count Register are cleared when the least significant byte of the register is loaded. This provides compatibility with software which accesses an 8237A. The 8237A has 16-bit Byte Count Registers.

NOTE:
The 82370 is a subset of the Intel 82380 32-bit DMA Controller with Integrated System Peripherals.

Although the 82370 has 24 address bits externally, the programming model is actually a full 32 bits wide. For this reason, there are some "hidden" DMA registers in the 82370 register set. These hidden registers correspond to what would be A24–A31 in a 32-bit system.

Think of the 82370 addresses as though they were 32 bits wide, with only the lower 24 bits available externally.

This should be of concern in two areas:

1. Understanding the Byte Pointer Flip Flop
2. Removing the IRQ1 Chaining Interrupt

The byte pointer flip flop will behave as though the hidden upper address bits were accessible.

The IRQ1 Chaining Interrupt will be removed only when the hidden upper address bits are programmed. You will note that since the hidden upper address bits are not available externally, the **value** you program into the registers is not important. The **act** of programming the hidden register is critical in removing the IRQ1 Chaining interrupt for a DMA channel.

The port assignments for these hidden upper address bits come directly from the port assignments of the Intel 82380. For your convenience, those port definitions have been included in this data sheet in section 3.7.

3.5.3 TEMPORARY REGISTERS

Each channel has a 32-bit Temporary Register used for temporary data storage during two-cycle DMA transfers. It is this register in which any necessary byte assembly and disassembly of non-aligned data is performed. Figure 3-22 shows how a block of data will be moved between memory locations with different boundaries. Note that the order of the data does not change.

If the destination is the Requester and an early process termination has been indicated by the EOP# signal or DREQn inactive in the Demand Mode, the Temporary Register is not affected. If data remains in the Temporary Register due to differences in data path widths of the Target and Requester, it will not be transferred or otherwise lost, but will be stored for later transfer.

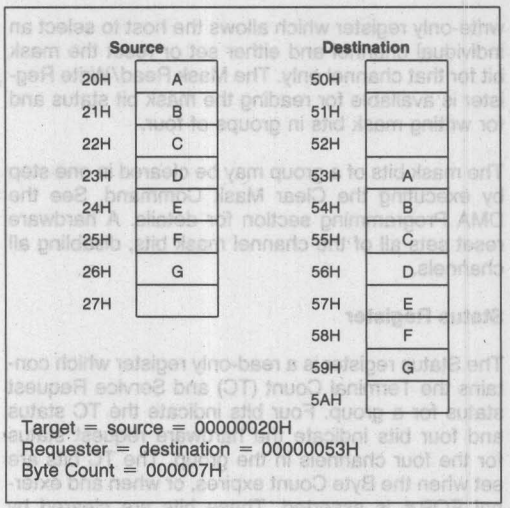


Figure 3-22. Transfer of data between memory locations with different boundaries. This will be the result, independent of data path width.

If the destination is the Target and the EOP# signal is sensed active during the Requester access of a transfer, the DMA Controller will complete the transfer by sending to the Target whatever information is in the Temporary Register at the time of process termination. This implies that the Target could be accessed with partial data in two accesses. For this reason it is advisable to have an I/O device designated as a Requester, unless it is capable of handling partial data transfers.

3.6 DMA Controller Programming

Programming a DMA Channel to perform a needed DMA function is in general a four step process. First the global attributes of the DMA Controller are programmed via the two Command Registers. These global attributes include: priority levels, channel group enables, priority mode, and DREQn/EOP# input sampling.

The second step involves setting the operating modes of the particular channel. The Mode Registers are used to define the type of transfer and the handshaking modes. The Bus Size Register and Chaining Register may also need to be programmed in this step.

The third step in setting up the channel is to load the Base Registers in accordance with the needs of the operating modes chosen in step two. The Current Registers are automatically loaded from the Base Registers, if required by the Buffer Transfer Mode in

effect. The information loaded and the order in which it is loaded depends on the operating mode. A channel used for cascading, for example, needs no buffer information and this step can be skipped entirely.

The last step is to enable the newly programmed channel using one of the Mask Registers. The channel is then available to perform the desired data transfer. The status of the channel can be observed at any time through the Status Register, Mask Register, Chaining Register, and Software Request register.

Once the channel is programmed and enabled, the DMA process may be initiated in one of two ways, either by a hardware DMA request (DREQn) or a software request (Software Request Register).

Once programmed to a particular Process/Mode configuration, the channel will operate in that configuration until programmed otherwise. For this reason, restarting a channel after the current buffer expires does not require complete reprogramming of the channel. Only those parameters which have changed need to be reprogrammed. The Byte Count Register is always changed and must be reprogrammed. A Target or Requester Address Register which is incremented or decremented should be reprogrammed also.

3.6.1 BUFFER PROCESSES

The Buffer Process is determined by the Auto-Initialize bit of Mode Register I and the Chaining Register. If Auto-Initialize is enabled, Chaining should not be used.

3.6.1.1 Single Buffer Process

The Single Buffer Process is programmed by disabling Chaining via the Chaining Register and programming Mode Register I for non-Auto-Initialize.

3.6.1.2 Buffer Auto-Initialize Process

Setting the Auto-Initialize bit in Mode Register I is all that is necessary to place the channel in this mode. Buffer Auto-Initialize must not be enabled simultaneous to enabling the Buffer Chaining Mode as this will have unpredictable results.

Once the Base Registers are loaded, the channel is ready to be enabled. The channel will reload its Current Registers from the Base Registers each time the Current Buffer expires, either by an expired Byte Count or an external EOP#.

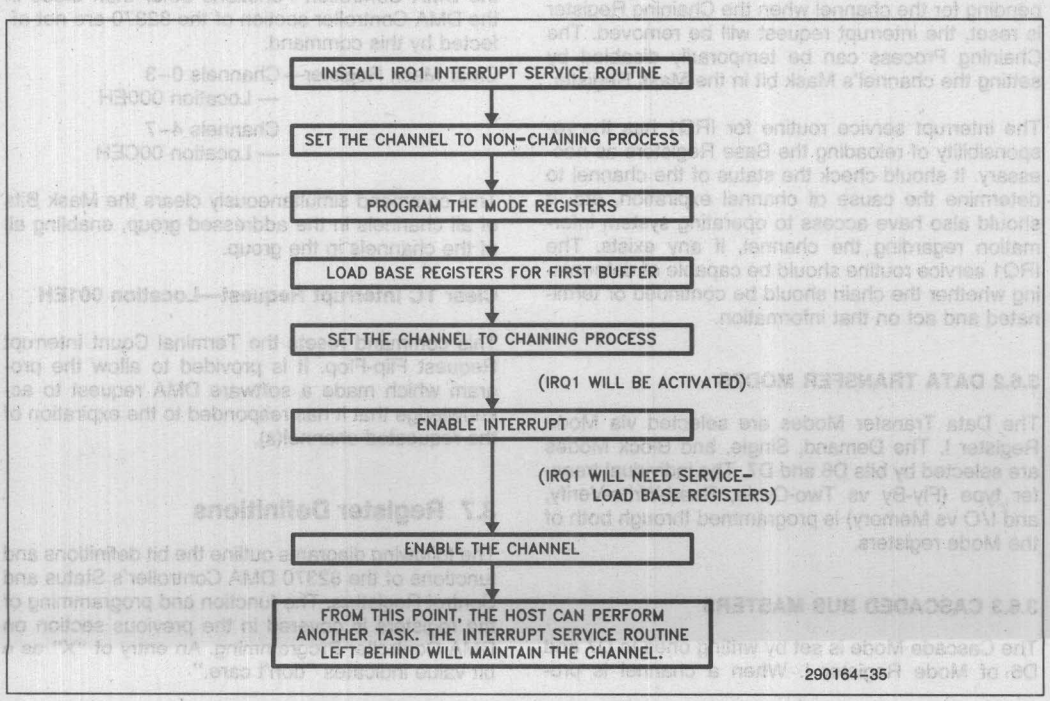


Figure 3-23. Flow of Events in the Buffer Chaining Process

3.6.1.3 Buffer Chaining Process

The Buffer Chaining Process is entered into from the Single Buffer Process. The Mode Registers should be programmed first, with all of the Transfer Modes defined as if the channel were to operate in the Single Buffer Process. The channel's Base Registers are then loaded. When the channel has been set up in this way, and the chaining interrupt service routine is in place, the Chaining Process can be entered by programming the Chaining Register. Figure 3-23 illustrates the Buffer Chaining Process.

An interrupt (IRQ1) will be generated immediately after the Chaining Process is entered, as the channel then perceives the Base Registers as empty and in need of reloading. It is important to have the interrupt service routine in place at the time the Chaining Process is entered into. The interrupt request is removed when the most significant byte of the Base Target Address is loaded.

The interrupt will occur again when the first buffer expires and the Current Registers are loaded from the Base Registers. The cycle continues until the Chaining Process is disabled, or the host fails to respond to IRQ1 before the Current Buffer expires.

Exiting the Chaining Process can be done by resetting the Chaining Mode Register. If an interrupt is pending for the channel when the Chaining Register is reset, the interrupt request will be removed. The Chaining Process can be temporarily disabled by setting the channel's Mask bit in the Mask Register.

The interrupt service routine for IRQ1 has the responsibility of reloading the Base Registers as necessary. It should check the status of the channel to determine the cause of channel expiration, etc. It should also have access to operating system information regarding the channel, if any exists. The IRQ1 service routine should be capable of determining whether the chain should be continued or terminated and act on that information.

3.6.2 DATA TRANSFER MODES

The Data Transfer Modes are selected via Mode Register I. The Demand, Single, and Block Modes are selected by bits D6 and D7. The individual transfer type (Fly-By vs Two-Cycle, Read-Write-Verify, and I/O vs Memory) is programmed through both of the Mode registers.

3.6.3 CASCADED BUS MASTERS

The Cascade Mode is set by writing ones to D7 and D6 of Mode Register I. When a channel is programmed to operate in the Cascade Mode, all of the other modes associated with Mode Registers I and II are ignored. The priority and DREQn/EOP# definitions of the Command Registers will have the same effect on the channel's operation as any other mode.

3.6.4 SOFTWARE COMMANDS

There are five port addresses which, when written to, command certain operations to be performed by the 82370 DMA Controller. The data written to these locations is not of consequence, writing to the location is all that is necessary to command the 82370 to perform the indicated function. Following are descriptions of the command functions.

Clear Byte Pointer Flip-Flop—Location 000CH

Resets the Byte Pointer Flip-Flop. This command should be performed at the beginning of any access to the channel registers in order to be assured of beginning at a predictable place in the register programming sequence.

Master Clear—Location 000DH

All DMA functions are set to their default states. This command is the equivalent of a hardware reset to the DMA Controller. Functions other than those in the DMA Controller section of the 82370 are not affected by this command.

Clear Mask Register— Channels 0–3
— Location 000EH
Channels 4–7
— Location 00CEH

This command simultaneously clears the Mask Bits of all channels in the addressed group, enabling all of the channels in the group.

Clear TC Interrupt Request—Location 001EH

This command resets the Terminal Count Interrupt Request Flip-Flop. It is provided to allow the program which made a software DMA request to acknowledge that it has responded to the expiration of the requested channel(s).

3.7 Register Definitions

The following diagrams outline the bit definitions and functions of the 82370 DMA Controller's Status and Control Registers. The function and programming of the registers is covered in the previous section on DMA Controller Programming. An entry of "X" as a bit value indicates "don't care."

Channel Registers (read Current, write Base)

Channel	Register Name	Address (hex)	Byte Pointer	Bits Accessed
Channel 0	Target Address	00	0	0–7
			1	8–15
		87	x	16–23
		10	0	24–31(*)
	Byte Count	01	0	0–7
			1	8–15
		11	0	16–23
	Requester Address	90	0	0–7
			1	8–15
		91	0	16–23
			1	24–31(*)
Channel 1	Target Address	02	0	0–7
			1	8–15
		83	x	16–23
		12	0	24–31(*)
	Byte Count	03	0	0–7
			1	8–15
		13	0	16–23
	Requester Address	92	0	0–7
			1	8–15
		93	0	16–23
			1	24–31(*)
Channel 2	Target Address	04	0	0–7
			1	8–15
		81	x	16–23
		14	0	24–31(*)
	Byte Count	05	0	0–7
			1	8–15
		15	0	16–23
	Requester Address	94	0	0–7
			1	8–15
		95	0	16–23
			1	24–31(*)
Channel 3	Target Address	06	0	0–7
			1	8–15
		82	x	16–23
		16	0	24–31(*)
	Byte Count	07	0	0–7
			1	8–15
		17	0	16–23
	Requester Address	96	0	0–7
			1	8–15
		97	0	16–23
			1	24–31(*)

9

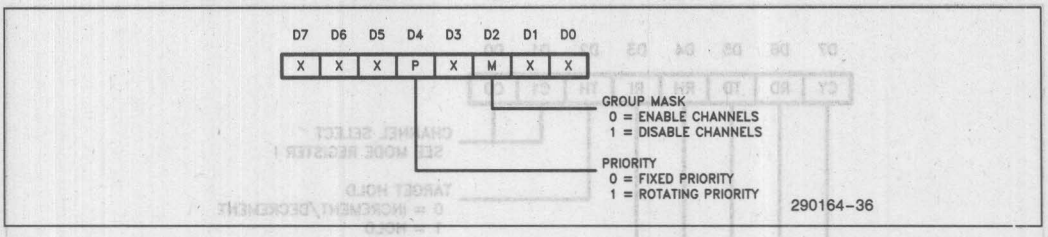
Channel Registers (read Current, write Base) (Continued)

Channel	Register Name	Address (hex)	Byte Pointer	Bits Accessed
Channel 4	Target Address	C0	0	0–7
			1	8–15
		8F	x	16–23
		D0	0	24–31(*)
	Byte Count	C1	0	0–7
			1	8–15
		D1	0	16–23
	Requester Address	98	0	0–7
			1	8–15
		99	0	16–23
			1	24–31(*)
Channel 5	Target Address	C2	0	0–7
			1	8–15
		8B	x	16–23
		D2	0	24–31(*)
	Byte Count	C3	0	0–7
			1	8–15
		D3	0	16–23
	Requester Address	9A	0	0–7
			1	8–15
		9B	0	16–23
			1	24–31(*)
Channel 6	Target Address	C4	0	0–7
			1	8–15
		89	x	16–23
		D4	0	24–31(*)
	Byte Count	C5	0	0–7
			1	8–15
		D5	0	16–23
	Requester Address	9C	0	0–7
			1	8–15
		9D	0	16–23
			1	24–31(*)
Channel 7	Target Address	C6	0	0–7
			1	8–15
		8A	x	16–23
		D6	0	24–31(*)
	Byte Count	C7	0	0–7
			1	8–15
		D7	0	16–23
	Requester Address	9E	0	0–7
			1	8–15
		9F	0	16–23
			1	24–31(*)

NOTE:
(*)*These bits are not available externally. You need to be aware of their existence for chaining and Byte Pointer Flip-Flop operations. Please see section 3.5.2 for further details.*

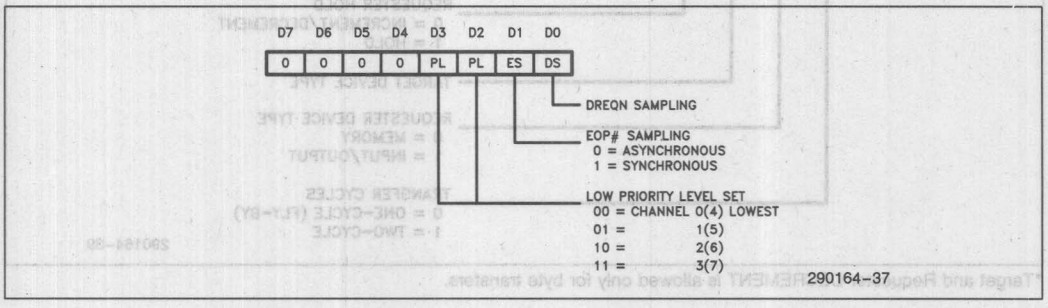
Command Register I (write only)

Port Addresses— Channels 0–3—0008H
Channels 4–7—00C8H



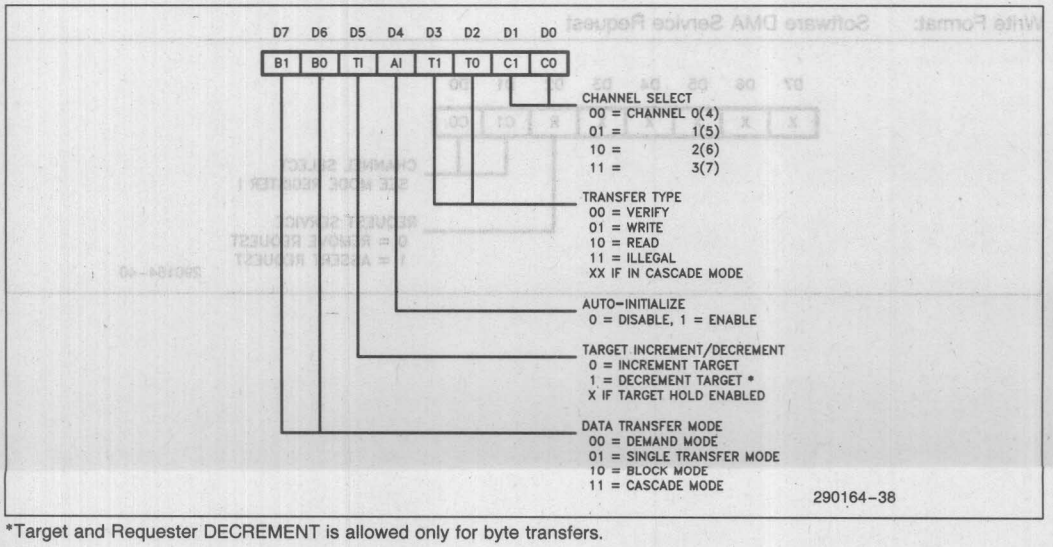
Command Register II (write only)

Port Addresses— Channels 0–3—001AH
Channels 4–7—00DAH



Mode Register I (write only)

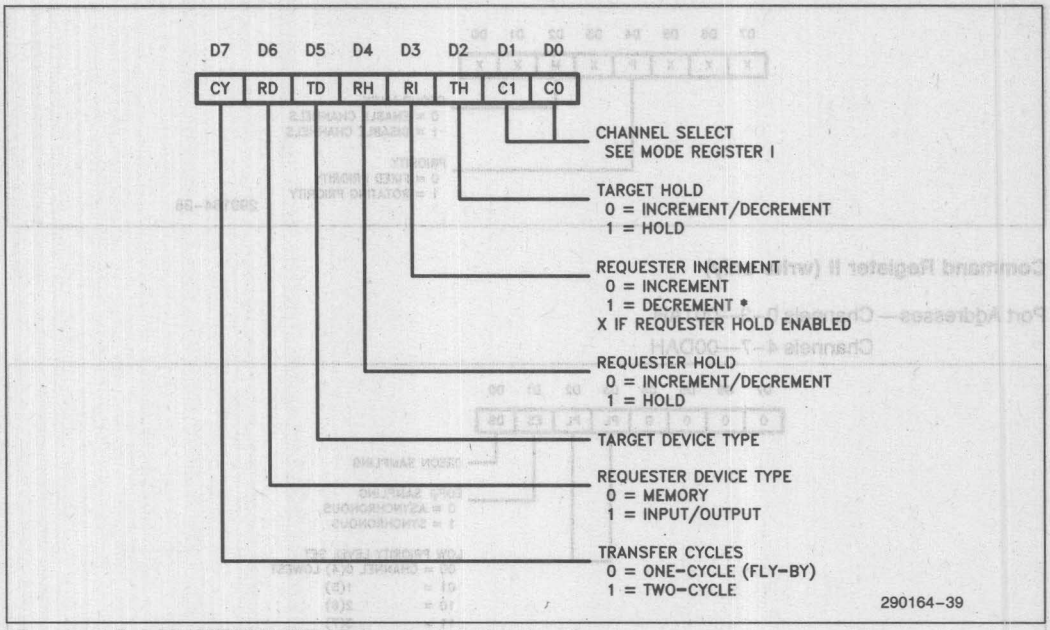
Port Addresses— Channels 0–3—000BH
Channels 4–7—00CBH



*Target and Requester DECREMENT is allowed only for byte transfers.

Mode Register II (write only)

Port Addresses— Channels 0–3—001BH
Channels 4–7—00DBH

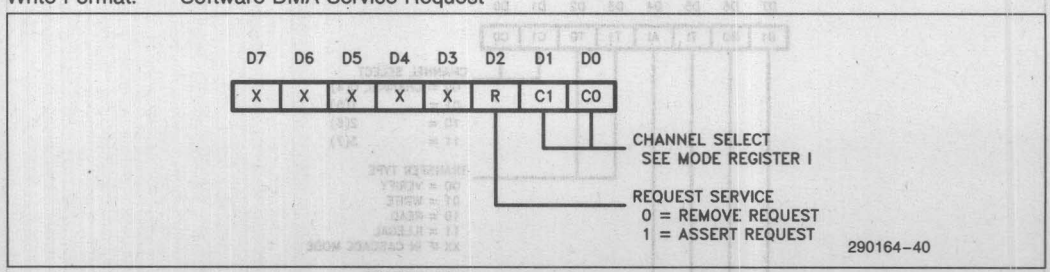


*Target and Requester DECREMENT is allowed only for byte transfers.

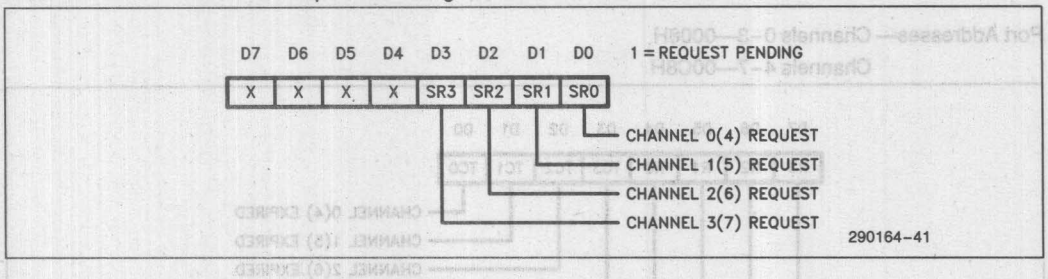
Software Request Register (read/write)

Port Addresses— Channels 0–3—0009H
Channels 4–7—00C9H

Write Format: Software DMA Service Request

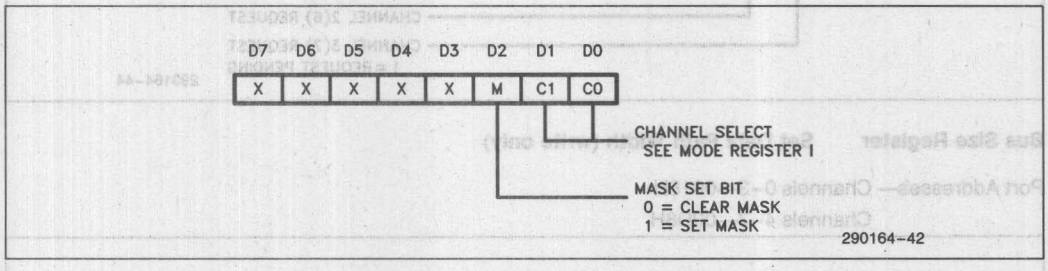


Read Format: Software Requests Pending



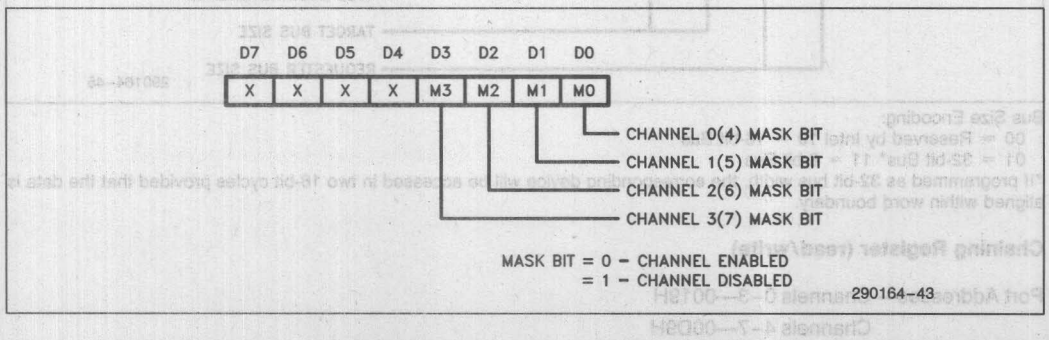
Mask Set/Reset Register **Individual Channel Mask (write only)**

Port Addresses— Channels 0–3—000AH
Channels 4–7—00CAH



Mask Read/Write Register **Group Channel Mask (read/write)**

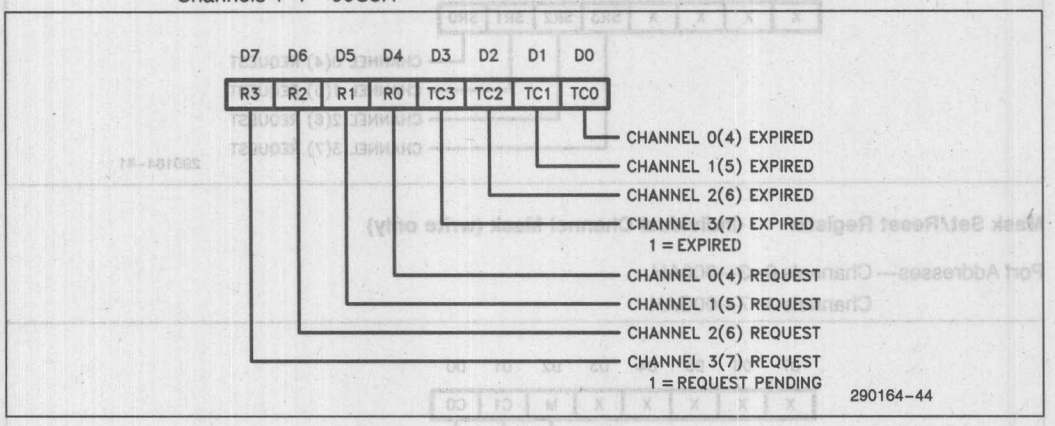
Port Addresses— Channels 0–3—000FH
Channels 4–7—00CFH



9

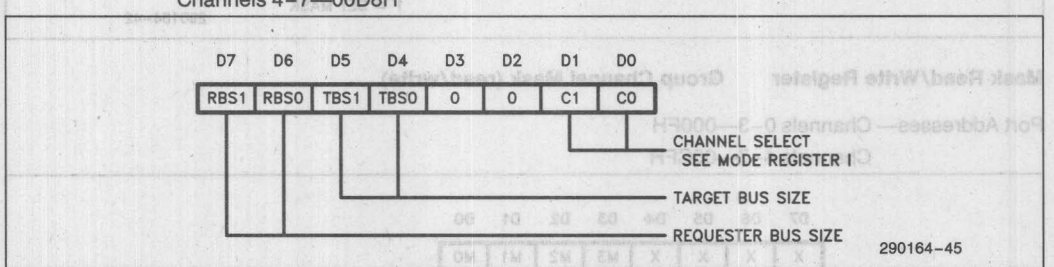
Status Register Channel Process Status (read only)

Port Addresses— Channels 0–3—0008H
Channels 4–7—00C8H



Bus Size Register Set Data Path Width (write only)

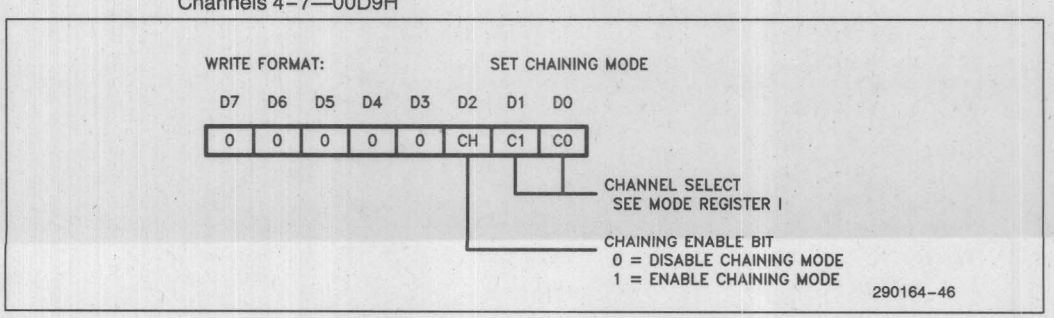
Port Addresses— Channels 0–3—0018H
Channels 4–7—00D8H

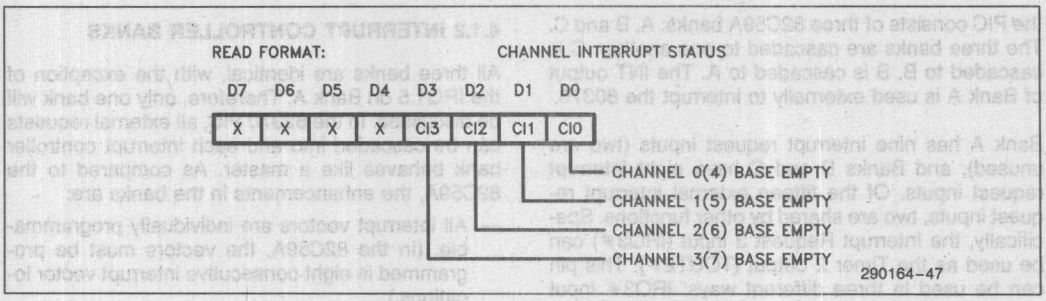


Bus Size Encoding:
00 = Reserved by Intel 10 = 16-bit Bus
01 = 32-bit Bus* 11 = 8-bit Bus
*If programmed as 32-bit bus width, the corresponding device will be accessed in two 16-bit cycles provided that the data is aligned within word boundary.

Chaining Register (read/write)

Port Addresses— Channels 0–3—0019H
Channels 4–7—00D9H





3.8 8237A Compatibility

The register arrangement of the 82370 DMA Controller is a superset of the 8237A DMA Controller. Functionally the 82370 DMA Controller is very different from the 8237A. Most of the functions of the 8237A are performed also by the 82370. The following discussion points out the differences between the 8237A and the 82370.

The 8237A is limited to transfers between I/O and memory only (except in one special case, where two channels can be used to perform memory-to-memory transfers). The 82370 DMA Controller can transfer between any combination of memory and I/O. Several other features of the 8237A are enhanced or expanded in the 82370 and other features are added.

The 8237A is an 8-bit only DMA device. For programming compatibility, all of the 8-bit registers are preserved in the 82370. The 82370 is programmed via 8-bit registers. The address registers in the 82370 are 24-bit registers in order to support the 80376's 24-bit bus. The Byte Count Registers are 24-bit registers, allowing support of larger data blocks than possible with the 8237A.

All of the 8237A's operating modes are supported by the 82370 (except the cumbersome two-channel memory-to-memory transfer). The 82370 performs memory-to-memory transfers using only one channel. The 82370 has the added features of buffer pipelining (Buffer Chaining Process) and programmable priority levels.

The 82370 also adds the feature of address registers for both destination and source. These addresses may be incremented, decremented, or held constant, as required by the application of the individual channel. This allows any combination of destination and source device.

Each DMA channel has associated with it a Target and a Requester. In the 8237A, the Target is the device which can be accessed by the address register, the Requester is the device which is accessed by the DMA Acknowledge signals and must be an I/O device.

4.0 PROGRAMMABLE INTERRUPT CONTROLLER (PIC)

4.1 Functional Description

The 82370 Programmable Interrupt Controller (PIC) consists of three enhanced 82C59A Interrupt Controllers. These three controllers together provide 15 external and 5 internal interrupt request inputs. Each external request input can be cascaded with an additional 82C59A slave controller. This scheme allows the 82370 to support a maximum of 120 (15 x 8) external interrupt request inputs.

Following one or more interrupt requests, the 82370 PIC issues an interrupt signal to the 80376. When the 80376 host processor responds with an interrupt acknowledge signal, the PIC will arbitrate between the pending interrupt requests and place the interrupt vector associated with the highest priority pending request on the data bus.

The major enhancement in the 82370 PIC over the 82C59A is that each of the interrupt request inputs can be individually programmed with its own interrupt vector, allowing more flexibility in interrupt vector mapping.

4.1.1 INTERNAL BLOCK DIAGRAM

The block diagram of the 82370 Programmable Interrupt Controller is shown in Figure 4-1. Internally,

9

the PIC consists of three 82C59A banks: A, B and C. The three banks are cascaded to one another: C is cascaded to B, B is cascaded to A. The INT output of Bank A is used externally to interrupt the 80376.

Bank A has nine interrupt request inputs (two are unused), and Banks B and C have eight interrupt request inputs. Of the fifteen external interrupt request inputs, two are shared by other functions. Specifically, the Interrupt Request 3 input (IRQ3#) can be used as the Timer 2 output (TOUT2#). This pin can be used in three different ways: IRQ3# input only, TOUT2# output only, or using TOUT2# to generate an IRQ3# interrupt request. Also, the Interrupt Request 9 input (IRQ9#) can be used as DMA Request 4 input (DREQ 4). Typically, only IRQ9# or DREQ4 can be used at a time.

4.1.2 INTERRUPT CONTROLLER BANKS

All three banks are identical, with the exception of the IRQ1.5 on Bank A. Therefore, only one bank will be discussed. In the 82370 PIC, all external requests can be cascaded into and each interrupt controller bank behaves like a master. As compared to the 82C59A, the enhancements in the banks are:

— All interrupt vectors are individually programmable. (In the 82C59A, the vectors must be programmed in eight consecutive interrupt vector locations.)

— The cascade address is provided on the Data Bus (D0-D7). (In the 82C59A, three dedicated control signals (CAS0, CAS1, CAS2) are used for master/slave cascading.)

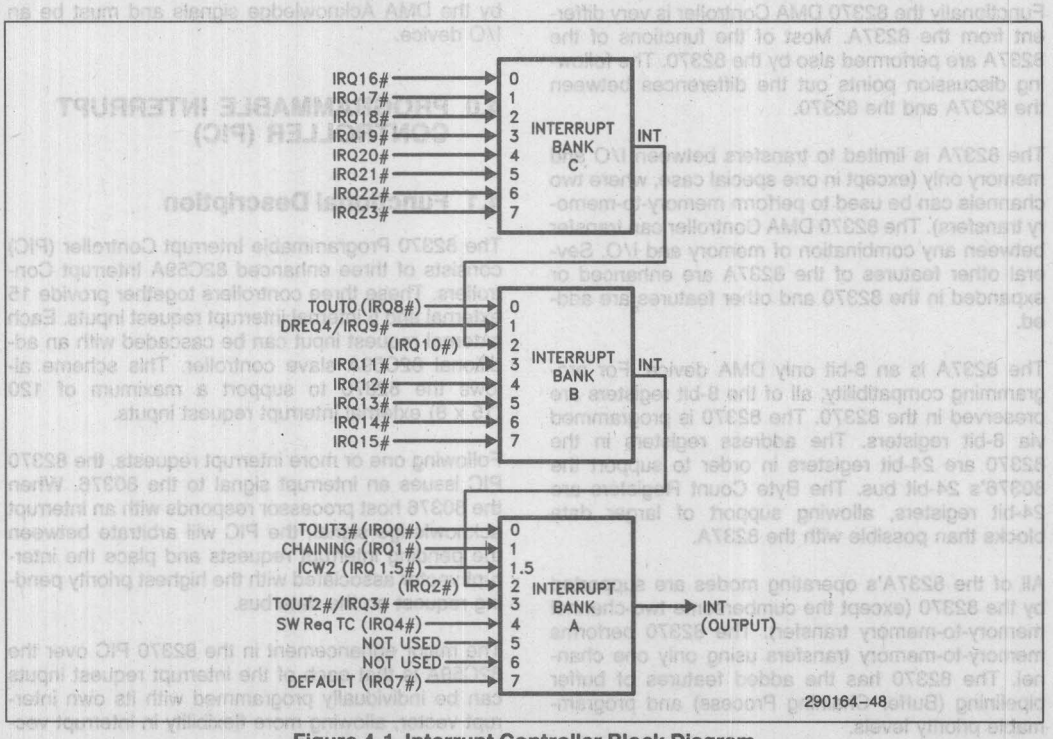


Figure 4-1. Interrupt Controller Block Diagram

The block diagram of a bank is shown in Figure 4-2. As can be seen from this figure, the bank consists of six major blocks: the Interrupt Request Register (IRR), the In-Service Register (ISR), the Interrupt Mask Register (IMR), the Priority Resolver (PR), the Vector Registers (VR), and the Control Logic. The functional description of each block is included below.

INTERRUPT REQUEST (IRR) AND IN-SERVICE REGISTER (ISR)

The interrupts at the Interrupt Request (IRQ) input lines are handled by two registers in cascade, the Interrupt Request Register (IRR) and the In-Service Register (ISR). The IRR is used to store all interrupt levels which are requesting service; and the ISR is used to store all interrupt levels which are being serviced.

PRIORITY RESOLVER (PR)

This logic block determines the priorities of the bits set in the IRR. The highest priority is selected and strobed into the corresponding bit of the ISR during an Interrupt Acknowledge cycle.

INTERRUPT MASK REGISTER (IMR)

The IMR stores the bits which mask the interrupt lines to be masked (disabled). The IMR operates on the IRR. Masking of a higher priority input will not affect the interrupt request lines of lower priority.

VECTOR REGISTERS (VR)

This block contains a set of Vector Registers, one for each interrupt request line, to store the pre-programmed interrupt vector number. The corresponding vector number will be driven onto the Data Bus of the 82370 during the Interrupt Acknowledge cycle.

CONTROL LOGIC

The Control Logic coordinates the overall operations of the other internal blocks within the same bank. This logic will drive the Interrupt Output signal (INT) HIGH when one or more unmasked interrupt inputs are active (LOW). The INT output signal goes directly to the 80376 (in bank A) or to another bank to which this bank is cascaded (see Figure 4-1). Also,

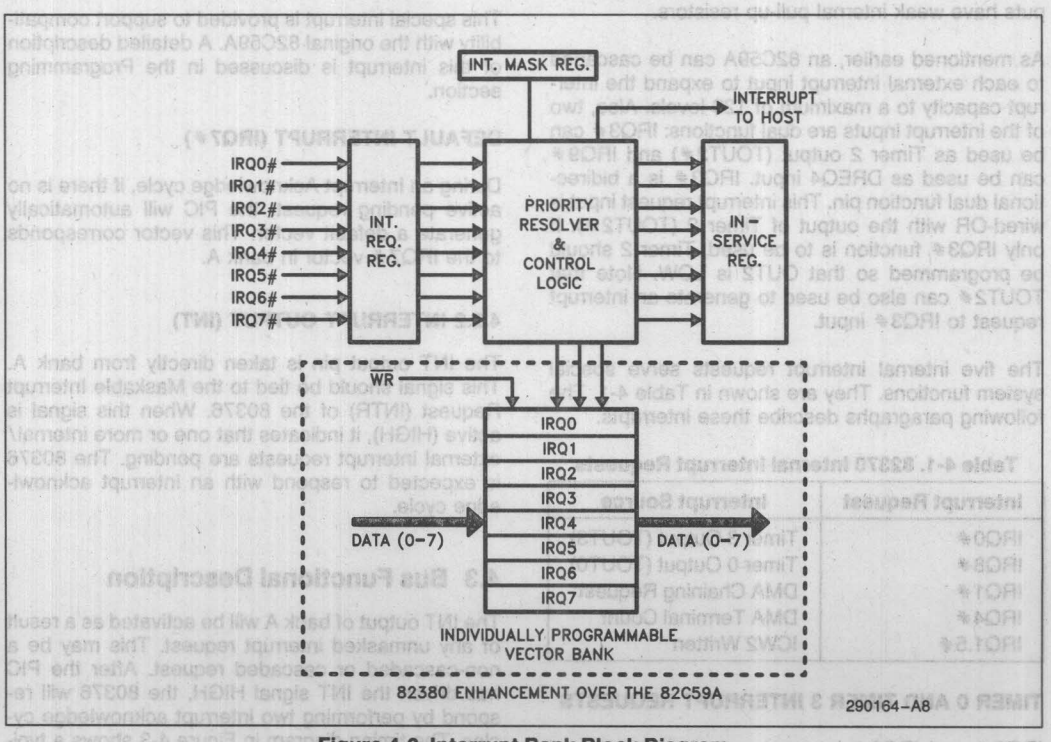


Figure 4-2. Interrupt Bank Block Diagram

this logic will recognize an Interrupt Acknowledge cycle (via M/IO#, D/C# and W/R# signals). During this bus cycle, the Control Logic will enable the corresponding Vector Register to drive the interrupt vector onto the Data Bus.

In bank A, the Control Logic is also responsible for handling the special ICW2 interrupt request input (IRQ1.5).

4.2 Interface Signals

4.2.1 INTERRUPT INPUTS

There are 15 external Interrupt Request inputs and 5 internal Interrupt Requests. The external request inputs are: IRQ3#, IRQ9#, IRQ11# to IRQ23#. They are shown in bold arrows in Figure 4-1. All IRQ inputs are active LOW and they can be programmed (via a control bit in the Initialization Command Word 1 (ICW1)) to be either edge-triggered or level-triggered. In order to be recognized as a valid interrupt request, the interrupt input must be active (LOW) until the first INTA cycle (see Bus Functional Description). Note that all 15 external Interrupt Request inputs have weak internal pull-up resistors.

As mentioned earlier, an 82C59A can be cascaded to each external interrupt input to expand the interrupt capacity to a maximum of 120 levels. Also, two of the interrupt inputs are dual functions: IRQ3# can be used as Timer 2 output (TOUT2#) and IRQ9# can be used as DREQ4 input. IRQ3# is a bidirectional dual function pin. This interrupt request input is wired-OR with the output of Timer 2 (TOUT2#). If only IRQ3# function is to be used, Timer 2 should be programmed so that OUT2 is LOW. Note that TOUT2# can also be used to generate an interrupt request to IRQ3# input.

The five internal interrupt requests serve special system functions. They are shown in Table 4-1. The following paragraphs describe these interrupts.

Table 4-1. 82370 Internal Interrupt Requests

Interrupt Request	Interrupt Source
IRQ0#	Timer 3 Output (TOUT3)
IRQ8#	Timer 0 Output (TOUT0)
IRQ1#	DMA Chaining Request
IRQ4#	DMA Terminal Count
IRQ1.5#	ICW2 Written

TIMER 0 AND TIMER 3 INTERRUPT REQUESTS

IRQ8# and IRQ0# interrupt requests are initiated by the output of Timers 0 and 3, respectively. Each of these requests is generated by an edge-detector flip-flop.

The flip-flops are activated by the following conditions:

Set — Rising edge of timer output (TOUT);

Clear — Interrupt acknowledge for this request; OR Request is masked (disabled); OR Hardware Reset.

CHAINING AND TERMINAL COUNT INTERRUPTS

These interrupt requests are generated by the 82370 DMA Controller. The chaining request (IRQ1#) indicates that the DMA Base Register is not loaded. The Terminal Count request (IRQ4#) indicates that a software DMA request was cleared.

ICW2 INTERRUPT REQUEST

Whenever an Initialization Control Word 2 (ICW2) is written to a Bank, a special ICW2 interrupt request is generated. The interrupt will be cleared when the newly programmed ICW2 Register is read. This interrupt request is in Bank A at level 1.5. This interrupt request is internally ORed with the Cascaded Request from Bank B and is always assigned a higher priority than the Cascaded Request.

This special interrupt is provided to support compatibility with the original 82C59A. A detailed description of this interrupt is discussed in the Programming section.

DEFAULT INTERRUPT (IRQ7#)

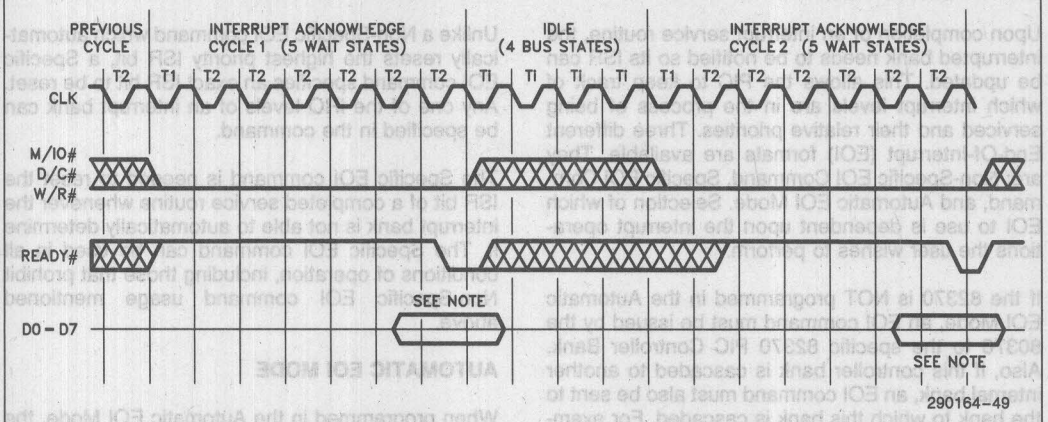
During an Interrupt Acknowledge cycle, if there is no active pending request, the PIC will automatically generate a default vector. This vector corresponds to the IRQ7# vector in bank A.

4.2.2 INTERRUPT OUTPUT (INT)

The INT output pin is taken directly from bank A. This signal should be tied to the Maskable Interrupt Request (INTR) of the 80376. When this signal is active (HIGH), it indicates that one or more internal/external interrupt requests are pending. The 80376 is expected to respond with an interrupt acknowledge cycle.

4.3 Bus Functional Description

The INT output of bank A will be activated as a result of any unmasked interrupt request. This may be a non-cascaded or cascaded request. After the PIC has driven the INT signal HIGH, the 80376 will respond by performing two interrupt acknowledge cycles. The timing diagram in Figure 4-3 shows a typical interrupt acknowledge process between the 82370 and the 80376 CPU.



NOTE:
What is actually driven on the Data Bus depends on if the current interrupt request is a Slave Request.

	INTA Cycle 1	INTA Cycle 2
NON-SLAVE REQUEST	00H	Vector
SLAVE REQUEST	Slave Address	High Impedence*

*Slave will place a vector at this time.

Figure 4-3. Interrupt Acknowledge Cycle

After activating the INT signal, the 82370 monitors the status lines (M/IO#, D/C#, W/R#) and waits for the 80376 to initiate the first interrupt acknowledge cycle. In the 80376 environment, two successive interrupt acknowledge cycles (INTA) marked by M/IO# = LOW, D/C# = LOW, and W/R# = LOW are performed. During the first INTA cycle, the PIC will determine the highest priority request. Assuming this interrupt input has no external Slave Controller cascaded to it, the 82370 will drive the Data Bus with 00H in the first INTA cycle. During the second INTA cycle, the 82370 PIC will drive the Data Bus with the corresponding pre-programmed interrupt vector.

If the PIC determines (from the ICW3) that this interrupt input has an external Slave Controller cascaded to it, it will drive the Data Bus with the specific Slave Cascade Address (instead of 00H) during the first INTA cycle. This Slave Cascade Address is the pre-programmed content in the corresponding Vector Register. This means that no Slave Address should be chosen to be 00H. Note that the Slave Address and Interrupt Vector are different interpretations of the same thing. They are both the contents of the programmable Vector Register. During the second INTA cycle, the Data Bus will be floated so that the external Slave Controller can drive its interrupt vector on the bus. Since the Slave Interrupt Controller resides on the system bus, bus transceiver enable and direction control logic must take this into consideration.

In order to have a successful interrupt service, the interrupt request input must be held valid (LOW) until the beginning of the first interrupt acknowledge cycle. If there is no pending interrupt request when the first INTA cycle is generated, the PIC will generate a default vector, which is the IRQ7 vector (Bank A, level 7).

According to the Bus Cycle definition of the 80376, there will be four Bus Idle States between the two interrupt acknowledge cycles. These idle bus cycles will be initiated by the 80376. Also, during each interrupt acknowledge cycle, the internal Wait State Generator of the 82370 will automatically generate the required number of wait states for internal delays.

4.4 Modes of Operation

A variety of modes and commands are available for controlling the 82370 PIC. All of them are programmable; that is, they may be changed dynamically under software control. In fact, each bank can be programmed individually to operate in different modes. With these modes and commands, many possible configurations are conceivable, giving the user enough versatility for almost any interrupt controlled application.

This section is not intended to show how the 82370 PIC can be programmed. Rather, it describes the operation in different modes.

4.4.1 END-OF-INTERRUPT

Upon completion of an interrupt service routine, the interrupted bank needs to be notified so its ISR can be updated. This allows the PIC to keep track of which interrupt levels are in the process of being serviced and their relative priorities. Three different End-Of-Interrupt (EOI) formats are available. They are: Non-Specific EOI Command, Specific EOI Command, and Automatic EOI Mode. Selection of which EOI to use is dependent upon the interrupt operations the user wishes to perform.

If the 82370 is NOT programmed in the Automatic EOI Mode, an EOI command must be issued by the 80376 to the specific 82370 PIC Controller Bank. Also, if this controller bank is cascaded to another internal bank, an EOI command must also be sent to the bank to which this bank is cascaded. For example, if an interrupt request of Bank C in the 82370 PIC is serviced, an EOI should be written into Bank C, Bank B and Bank A. If the request comes from an external interrupt controller cascaded to Bank C, then an EOI should be written into the external controller as well.

NON-SPECIFIC EOI COMMAND

A Non-Specific EOI command sent from the 80376 lets the 82370 PIC bank know when a service routine has been completed, without specification of its exact interrupt level. The respective interrupt bank automatically determines the interrupt level and resets the correct bit in the ISR.

To take advantage of the Non-Specific EOI, the interrupt bank must be in a mode of operation in which it can predetermine its in-service routine levels. For this reason, the Non-Specific EOI command should only be used when the most recent level acknowledged and serviced is always the highest priority level (i.e. in the Fully Nested Mode structure to be described below). When the interrupt bank receives a Non-Specific EOI command, it simply resets the highest priority ISR bit to indicate that the highest priority routine in service is finished.

Special consideration should be taken when deciding to use the Non-Specific EOI command. Here are two operating conditions in which it is best NOT used since the Fully Nested Mode structure will be destroyed:

— Using the Set Priority command within an interrupt service routine.

— Using a Special Mask Mode.

These conditions are covered in more detail in their own sections, but are listed here for reference.

SPECIFIC EOI COMMAND

Unlike a Non-Specific EOI command which automatically resets the highest priority ISR bit, a Specific EOI command specifies an exact ISR bit to be reset. Any one of the IRQ levels of an interrupt bank can be specified in the command.

The Specific EOI command is needed to reset the ISR bit of a completed service routine whenever the interrupt bank is not able to automatically determine it. The Specific EOI command can be used in all conditions of operation, including those that prohibit Non-Specific EOI command usage mentioned above.

AUTOMATIC EOI MODE

When programmed in the Automatic EOI Mode, the 80376 no longer needs to issue a command to notify the interrupt bank it has completed an interrupt routine. The interrupt bank accomplishes this by performing a Non-Specific EOI automatically at the end of the second INTA cycle.

Special consideration should be taken when deciding to use the Automatic EOI Mode because it may disturb the Fully Nested Mode structure. In the Automatic EOI Mode, the ISR bit of a routine in service is reset right after it is acknowledged, thus leaving no designation in the ISR that a service routine is being executed. If any interrupt request within the same bank occurs during this time and interrupts are enabled, it will get serviced regardless of its priority. Therefore, when using this mode, the 80376 should keep its interrupt request input disabled during execution of a service routine. By doing this, higher priority interrupt levels will be serviced only after the completion of a routine in service. This guideline restores the Fully Nested Mode structure. However, in this scheme, a routine in service cannot be interrupted since the host's interrupt request input is disabled.

4.4.2 INTERRUPT PRIORITIES

The 82370 PIC provides various methods for arranging the interrupt priorities of the interrupt request inputs to suit different applications. The following subsections explain these methods in detail.

4.4.2.1 Fully Nested Mode

The Fully Nested Mode of operation is a general purpose priority mode. This mode supports a multi-level interrupt structure in which all of the Interrupt Request (IRQ) inputs within one bank are arranged from highest to lowest.

Unless otherwise programmed, the Fully Nested Mode is entered by default upon initialization. At this time, IRQ0# is assigned the highest priority (priority = 0) and IRQ7# the lowest (priority = 7). This default priority can be changed, as will be explained later in the Rotating Priority Mode.

When an interrupt is acknowledged, the highest priority request is determined from the Interrupt Request Register (IRR) and its vector is placed on the bus. In addition, the corresponding bit in the In-Service Register (ISR) is set to designate the routine in service. This ISR bit will remain set until the 80376 issues an End Of Interrupt (EOI) command immediately before returning from the service routine; or alternately, if the Automatic End Of Interrupt (AEOI) bit is set, the ISR bit will be reset at the end of the second INTA cycle.

While the ISR bit is set, all further interrupts of the same or lower priority are inhibited. Higher level interrupts can still generate an interrupt, which will be acknowledged only if the 80376 internal interrupt enable flip-flop has been reenabled (through software inside the current service routine).

4.4.2.2 Automatic Rotation–Equal Priority Devices

Automatic rotation of priorities serves in applications where the interrupting devices are of equal priority within an interrupt bank. In this kind of environment, once a device is serviced, all other equal priority peripherals should be given a chance to be serviced before the original device is serviced again. This is accomplished by automatically assigning a device the lowest priority after being serviced. Thus, in the worst case, the device would have to wait until all other peripherals connected to the same bank are serviced before it is serviced again.

There are two methods of accomplishing automatic rotation. One is used in conjunction with the Non-Specific EOI command and the other is used with the Automatic EOI mode. These two methods are discussed below.

ROTATE ON NON-SPECIFIC EOI COMMAND

When the Rotate On Non-Specific EOI command is issued, the highest ISR bit is reset as in a normal Non-Specific EOI command. However, after it is reset, the corresponding Interrupt Request (IRQ) level is assigned the lowest priority. Other IRQ priorities rotate to conform to the Fully Nested Mode based on the newly assigned low priority.

Figure 4-4 shows how the Rotate On Non-Specific EOI command affects the interrupt priorities. Assume the IRQ priorities were assigned with IRQ0 the highest and IRQ7 the lowest. IRQ6 and IRQ4 are

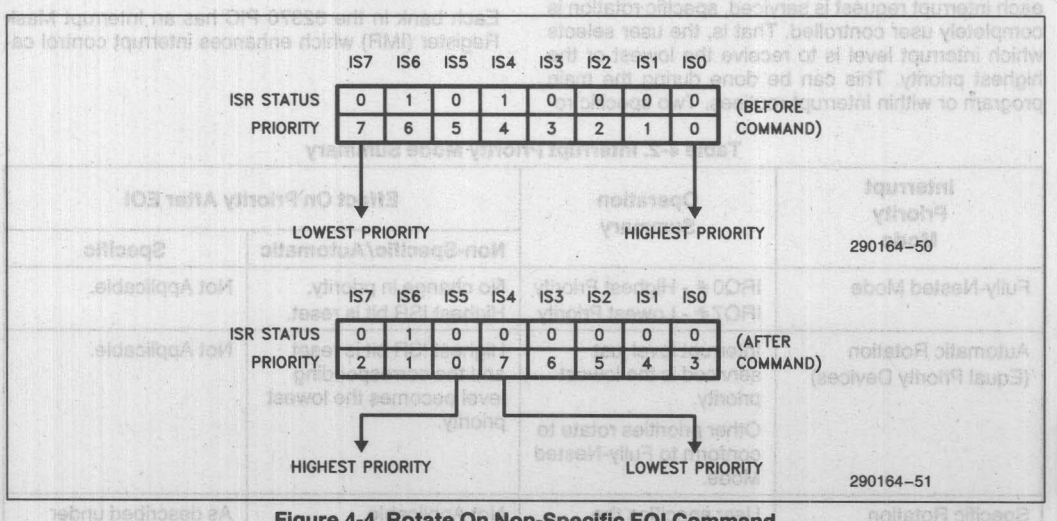


Figure 4-4. Rotate On Non-Specific EOI Command

9

already in service but neither is completed. Being the higher priority routine, IRQ4 is necessarily the routine being executed. During the IRQ4 routine, a rotate on Non-Specific EOI command is executed. When this happens, Bit 4 in the ISR is reset. IRQ4 then becomes the lowest priority and IRQ5 becomes the highest.

ROTATE ON AUTOMATIC EOI MODE

The Rotate On Automatic EOI Mode works much like the Rotate On Non-Specific EOI Command. The main difference is that priority rotation is done automatically after the second INTA cycle of an interrupt request. To enter or exit this mode, a Rotate-On-Automatic-EOI Set Command and Rotate-On-Automatic-EOI Clear Command is provided. After this mode is entered, no other commands are needed as in the normal Automatic EOI Mode. However, it must be noted again that when using any form of the Automatic EOI Mode, special consideration should be taken. The guideline presented in the Automatic EOI Mode also applies here.

4.4.2.3 Specific Rotation–Specific Priority

Specific rotation gives the user versatile capabilities in interrupt controlled operations. It serves in those applications in which a specific device's interrupt priority must be altered. As opposed to Automatic Rotation which will automatically set priorities after each interrupt request is serviced, specific rotation is completely user controlled. That is, the user selects which interrupt level is to receive the lowest or the highest priority. This can be done during the main program or within interrupt routines. Two specific rotation commands are available to the user: Set Priority Command and Rotate On Specific EOI Command.

SET PRIORITY COMMAND

The Set Priority Command allows the programmer to assign an IRQ level the lowest priority. All other interrupt levels will conform to the Fully Nested Mode based on the newly assigned low priority.

ROTATE ON SPECIFIC EOI COMMAND

The Rotate On Specific EOI Command is literally a combination of the Set Priority Command and the Specific EOI Command. Like the Set Priority Command, a specified IRQ level is assigned lowest priority. Like the Specific EOI Command, a specified level will be reset in the ISR. Thus, this command accomplishes both tasks in one single command.

4.4.2.4 Interrupt Priority Mode Summary

In order to simplify understanding the many modes of interrupt priority, Table 4-2 is provided to bring out their summary of operations.

4.4.3 INTERRUPT MASKING

VIA INTERRUPT MASK REGISTER

Each bank in the 82370 PIC has an Interrupt Mask Register (IMR) which enhances interrupt control ca-

Table 4-2. Interrupt Priority Mode Summary

Interrupt Priority Mode	Operation Summary	Effect On Priority After EOI	
		Non-Specific/Automatic	Specific
Fully-Nested Mode	IRQ0# - Highest Priority IRQ7# - Lowest Priority	No change in priority. Highest ISR bit is reset.	Not Applicable.
Automatic Rotation (Equal Priority Devices)	Interrupt level just serviced is the lowest priority. Other priorities rotate to conform to Fully-Nested Mode.	Highest ISR bit is reset and the corresponding level becomes the lowest priority.	Not Applicable.
Specific Rotation (Specific Priority Devices)	User specifies the lowest priority level. Other priorities rotate to conform to Fully-Nested Mode.	Not Applicable.	As described under "Operation Summary".

pabilities. This IMR allows individual IRQ masking. When an IRQ is masked, its interrupt request is disabled until it is unmasked. Each bit in the 8-bit IMR disables one interrupt channel if it is set (HIGH). Bit 0 masks IRQ0, Bit 1 masks IRQ1 and so forth. Masking an IRQ channel will only disable the corresponding channel and does not affect the others' operations.

The IMR acts only on the output of the IRR. That is, if an interrupt occurs while its IMR bit is set, this request is not "forgotten". Even with an IRQ input masked, it is still possible to set the IRR. Therefore, when the IMR bit is reset, an interrupt request to the 80376 will then be generated, providing that the IRQ request remains active. If the IRQ request is removed before the IMR is reset, the Default Interrupt Vector (Bank A, level 7) will be generated during the interrupt acknowledge cycle.

SPECIAL MASK MODE

In the Fully Nested Mode, all IRQ levels of lower priority than the routine in service are inhibited. However, in some applications, it may be desirable to let a lower priority interrupt request to interrupt the routine in service. One method to achieve this is by using the Special Mask Mode. Working in conjunction with the IMR, the Special Mask Mode enables interrupts from all levels except the level in service. This is usually done inside an interrupt service routine by masking the level that is in service and then issuing the Special Mask Mode Command. Once the Special Mask Mode is enabled, it remains in effect until it is disabled.

4.4.4 EDGE OR LEVEL INTERRUPT TRIGGERING

Each bank in the 82370 PIC can be programmed independently for either edge or level sensing for the interrupt request signals. Recall that all IRQ inputs are active LOW. Therefore, in the edge triggered mode, an active edge is defined as an input transition from an inactive (HIGH) to active (LOW) state. The interrupt input may remain active without generating another interrupt. During level triggered mode, an interrupt request will be recognized by an active (LOW) input, and there is no need for edge detection. However, the interrupt request must be removed before the EOI Command is issued, or the 80376 must be disabled to prevent a second false interrupt from occurring.

In either modes, the interrupt request input must be active (LOW) during the first INTA cycle in order to be recognized. Otherwise, the Default Interrupt Vector will be generated at level 7 of Bank A.

4.4.5 INTERRUPT CASCADING

As mentioned previously, the 82370 allows for external Slave interrupt controllers to be cascaded to any of its external interrupt request pins. The 82370 PIC indicates that an external Slave Controller is to be serviced by putting the contents of the Vector Register associated with the particular request on the 80376 Data Bus during the first INTA cycle (instead of 00H during a non-slave service). The external logic should latch the vector on the Data Bus using the INTA status signals and use it to select the external Slave Controller to be serviced (see Figure 4-5). The selected Slave will then respond to the second INTA cycle and place its vector on the Data Bus. This method requires that if external Slave Controllers are used in the system, no vector should be programmed to 00H.

Since the external Slave Cascade Address is provided on the Data Bus during INTA cycle 1, an external latch is required to capture this address for the Slave Controller. A simple scheme is depicted in Figure 4-5 below.

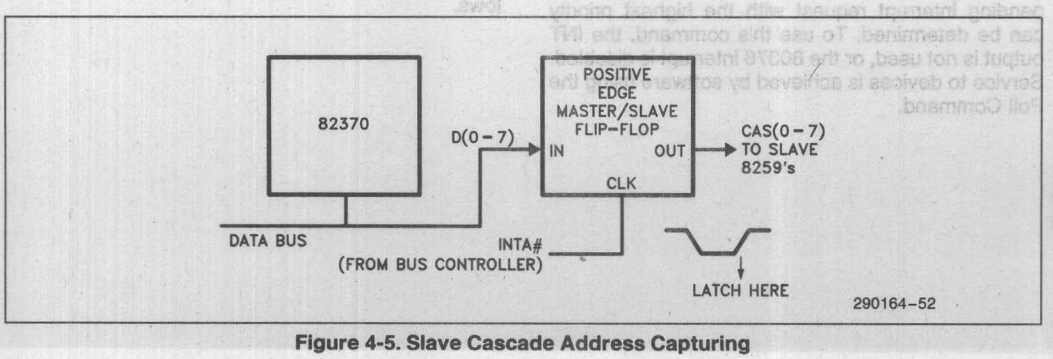


Figure 4-5. Slave Cascade Address Capturing

4.4.5.1 Special Fully Nested Mode

This mode will be used where cascading is employed and the priority is to be conserved within each Slave Controller. The Special Fully Nested Mode is similar to the "regular" Fully Nested Mode with the following exceptions:

— When an interrupt request from a Slave Controller is in service, this Slave Controller is not locked out from the Master's priority logic. Further interrupt requests from the higher priority logic within the Slave Controller will be recognized by the 82370 PIC and will initiate interrupts to the 80376. In comparing to the "regular" Fully Nested Mode, the Slave Controller is masked out when its request is in service and no higher requests from the same Slave Controller can be serviced.

— Before exiting the interrupt service routine, the software has to check whether the interrupt serviced was the only request from the Slave Controller. This is done by sending a Non-Specific EOI Command to the Slave Controller and then reading its In Service Register. If there are no requests in the Slave Controller, a Non-Specific EOI can be sent to the corresponding 82370 PIC bank also. Otherwise, no EOI should be sent.

4.4.6 READING INTERRUPT STATUS

The 82370 PIC provides several ways to read different status of each interrupt bank for more flexible interrupt control operations. These include polling the highest priority pending interrupt request and reading the contents of different interrupt status registers.

4.4.6.1 Poll Command

The 82370 PIC supports status polling operations with the Poll Command. In a Poll Command, the pending interrupt request with the highest priority can be determined. To use this command, the INT output is not used, or the 80376 interrupt is disabled. Service to devices is achieved by software using the Poll Command.

This mode is useful if there is a routine command common to several levels so that the INTA sequence is not needed. Another application is to use the Poll Command to expand the number of priority levels.

Notice that the ICW2 mechanism is not supported for the Poll Command. However, if the Poll Command is used, the programmable Vector Registers are of no concern since no INTA cycle will be generated.

4.4.6.2 Reading Interrupt Registers

The contents of each interrupt register (IRR, ISR, and IMR) can be read to update the user's program on the present status of the 82370 PIC. This can be a versatile tool in the decision making process of a service routine, giving the user more control over interrupt operations.

The reading of the IRR and ISR contents can be performed via the Operation Control Word 3 by using a Read Status Register Command and the content of IMR can be read via a simple read operation of the register itself.

4.5 Register Set Overview

Each bank of the 82370 PIC consists of a set of 8-bit registers to control its operations. The address map of all the registers is shown in Table 4-3 below. Since all three register sets are identical in functions, only one set will be described.

Functionally, each register set can be divided into five groups. They are: the four Initialization Command Words (ICW's), the three Operation Control Words (OCW's), the Poll/Interrupt Request/In-Service Register, the Interrupt Mask Register, and the Vector Registers. A description of each group follows.

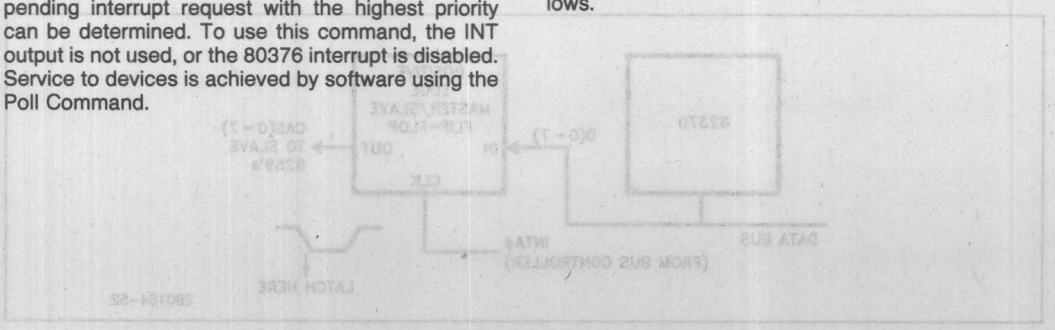


Table 4-3. Interrupt Controller Register Address Map

Port Address	Access	Register Description
20H	Write	Bank B ICW1, OCW2, or OCW3
	Read	Bank B Poll, Request or In-Service Status Register
21H	Write	Bank B ICW2, ICW3, ICW4, OCW1
	Read	Bank B Mask Register
22H	Read	Bank B ICW2
28H	Read/Write	IRQ8 Vector Register
29H	Read/Write	IRQ9 Vector Register
2AH	Read/Write	Reserved
2BH	Read/Write	IRQ11 Vector Register
2CH	Read/Write	IRQ12 Vector Register
2DH	Read/Write	IRQ13 Vector Register
2EH	Read/Write	IRQ14 Vector Register
2FH	Read/Write	IRQ15 Vector Register
A0H	Write	Bank C ICW1, OCW2, or OCW3
	Read	Bank C Poll, Request or In-Service Status Register
A1H	Write	Bank C ICW2, ICW3, ICW4, OCW1
	Read	Bank C Mask Register
A2H	Read	Bank C ICW2
A8H	Read/Write	IRQ16 Vector Register
A9H	Read/Write	IRQ17 Vector Register
AAH	Read/Write	IRQ18 Vector Register
ABH	Read/Write	IRQ19 Vector Register
ACH	Read/Write	IRQ20 Vector Register
ADH	Read/Write	IRQ21 Vector Register
AEH	Read/Write	IRQ22 Vector Register
AFH	Read/Write	IRQ23 Vector Register
30H	Write	Bank A ICW1, OCW2, or OCW3
	Read	Bank A Poll, Request or In-Service Status Register
31H	Write	Bank A ICW2, ICW3, ICW4, OCW1
	Read	Bank A Mask Register
32H	Read	Bank ICW2
38H	Read/Write	IRQ0 Vector Register
39H	Read/Write	IRQ1 Vector Register
3AH	Read/Write	IRQ1.5 Vector Register
3BH	Read/Write	IRQ3 Vector Register
3CH	Read/Write	IRQ4 Vector Register
3DH	Read/Write	Reserved
3EH	Read/Write	Reserved
3FH	Read/Write	IRQ7 Vector Register

4.5.1 INITIALIZATION COMMAND WORDS (ICW)

Before normal operation can begin, the 82370 PIC must be brought to a known state. There are four 8-bit Initialization Command Words in each interrupt bank to setup the necessary conditions and modes for proper operation. Except for the second command word (ICW2) which is a read/write register, the other three are write-only registers. Without going into detail of the bit definitions of the command words, the following subsections give a brief description of what functions each command word controls.

ICW1

The ICW1 has three major functions. They are:

— To select between the two IRQ input triggering modes (edge- or level-triggered);

— To designate whether or not the interrupt bank is to be used alone or in the cascade mode. If the cascade mode is desired, the interrupt bank will accept ICW3 for further cascade mode programming. Otherwise, no ICW3 will be accepted;

— To determine whether or not ICW4 will be issued; that is, if any of the ICW4 operations are to be used.

ICW2

ICW2 is provided for compatibility with the 82C59A only. Its contents do not affect the operation of the interrupt bank in any way. Whenever the ICW2 of any of the three banks is written into, an interrupt is generated from bank A at level 1.5. The interrupt request will be cleared after the ICW2 register has been read by the 80376. The user is expected to program the corresponding vector register or to use it as an indicator that an attempt was made to alter the contents. Note that each ICW2 register has different addresses for read and write operations.

ICW3

The interrupt bank will only accept an ICW3 if programmed in the external cascade mode (as indicated in ICW1). ICW3 is used for specific programming within the cascade mode. The bits in ICW3 indicate which interrupt request inputs have a Slave cascaded to them. This will subsequently affect the interrupt vector generation during the interrupt acknowledge cycles as described previously.

ICW4

The ICW4 is accepted only if it was selected in ICW1. This command word register serves two functions:

— To select either the Automatic EOI mode or software EOI mode;

— To select if the Special Nested mode is to be used in conjunction with the cascade mode.

4.5.2 OPERATION CONTROL WORDS (OCW)

Once initialized by the ICW's, the interrupt banks will be operating in the Fully Nested Mode by default and they are ready to accept interrupt requests. However, the operations of each interrupt bank can be further controlled or modified by the use of OCW's. Three OCW's are available for programming various modes and commands. Note that all OCW's are 8-bit write-only registers.

The modes and operations controlled by the OCW's are:

— Fully Nested Mode;

— Rotating Priority Mode;

— Special Mask Mode;

— Poll Mode;

— EOI Commands;

— Read Status Commands.

OCW1

OCW1 is used solely for masking operations. It provides a direct link to the Internal Mask Register (IMR). The 80376 can write to this OCW register to enable or disable the interrupt inputs. Reading the pre-programmed mask can be done via the Interrupt Mask Register which will be discussed shortly.

OCW2

OCW2 is used to select End-Of-Interrupt, Automatic Priority Rotation, and Specific Priority Rotation operations. Associated commands and modes of these operations are selected using the different combinations of bits in OCW2.

Specifically, the OCW2 is used to:

— Designate an interrupt level (0–7) to be used to reset a specific ISR bit or to set a specific priority. This function can be enabled or disabled;

— Select which software EOI command (if any) is to be executed (i.e. Non-Specific or Specific EOI);

— Enable one of the priority rotation operations (i.e. Rotate On Non-Specific EOI, Rotate On Automatic EOI, or Rotate On Specific EOI).

OCW3

There are three main categories of operation that OCW3 controls. They are summarized as follows:

— To select and execute the Read Status Register Commands, either reading the Interrupt Request Register (IRR) or the In-Service Register (ISR);

— To issue the Poll Command. The Poll Command will override a Read Register Command if both functions are enabled simultaneously;

— To set or reset the Special Mask Mode.

4.5.3 POLL/INTERRUPT REQUEST/IN-SERVICE STATUS REGISTER

As the name implies, this 8-bit read-only register has multiple functions. Depending on the command issued in the OCW3, the content of this register reflects the result of the command executed. For a Poll Command, the register read contains the binary code of the highest priority level requesting service (if any). For a Read IRR Command, the register content will show the current pending interrupt request(s). Finally, for a Read ISR Command, this register will specify all interrupt levels which are being serviced.

4.5.4 INTERRUPT MASK REGISTER (IMR)

This is a read-only 8-bit register which, when read, will specify all interrupt levels within the same bank that are masked.

4.5.5 VECTOR REGISTERS (VR)

Each interrupt request input has an 8-bit read/write programmable vector register associated with it. The registers should be programmed to contain the interrupt vector for the corresponding request. The contents of the Vector Register will be placed on the Data Bus during the INTA cycles as described previously.

4.6 Programming

Programming the 82370 PIC is accomplished by using two types of command words: ICW's and OCW's. All modes and commands explained in the previous sections are programmable using the ICW's and OCW's. The ICW's are issued from the 80376 in a sequential format and are used to setup the banks in the 82370 PIC in an initial state of operation. The OCW's are issued as needed to vary and control the 82370 PIC's operations.

Both ICW's and OCW's are sent by the 80376 to the interrupt banks via the Data Bus. Each bank distinguishes between the different ICW's and OCW's by the I/O address map, the sequence they are issued (ICW's only), and by some dedicated bits among the ICW's and OCW's.

An example of programming the 82370 interrupt controllers is given in Appendix C (Programming the 82370 Interrupt Controllers).

All three interrupt banks are programmed in a similar way. Therefore, only a single bank will be described in the following sections.

4.6.1 INITIALIZATION (ICW)

Before normal operation can begin, each bank must be initialized by programming a sequence of two to four bytes written into the ICW's.

Figure 4-6 shows the initialization flow for an interrupt bank. Both ICW1 and ICW2 must be issued for any form of operation. However, ICW3 and ICW4 are used only if designated in ICW1. Once initialized, if any programming changes within the ICW's are to be made, the entire ICW sequence must be reprogrammed, not just an individual ICW.

Note that although the ICW2's in the 82370 PIC do not effect the Bank's operation, they still must be programmed in order to preserve the compatibility with the 82C59A. The contents programmed are not relevant to the overall operations of the interrupt banks. Also, whenever one of the three ICW2's is programmed, an interrupt level 1.5 in Bank A will be generated. This interrupt request will be cleared upon reading of the ICW2 registers. Since the three ICW2's share the same interrupt level and the system may not know the origin of the interrupt, all three ICW2's must be read.

9

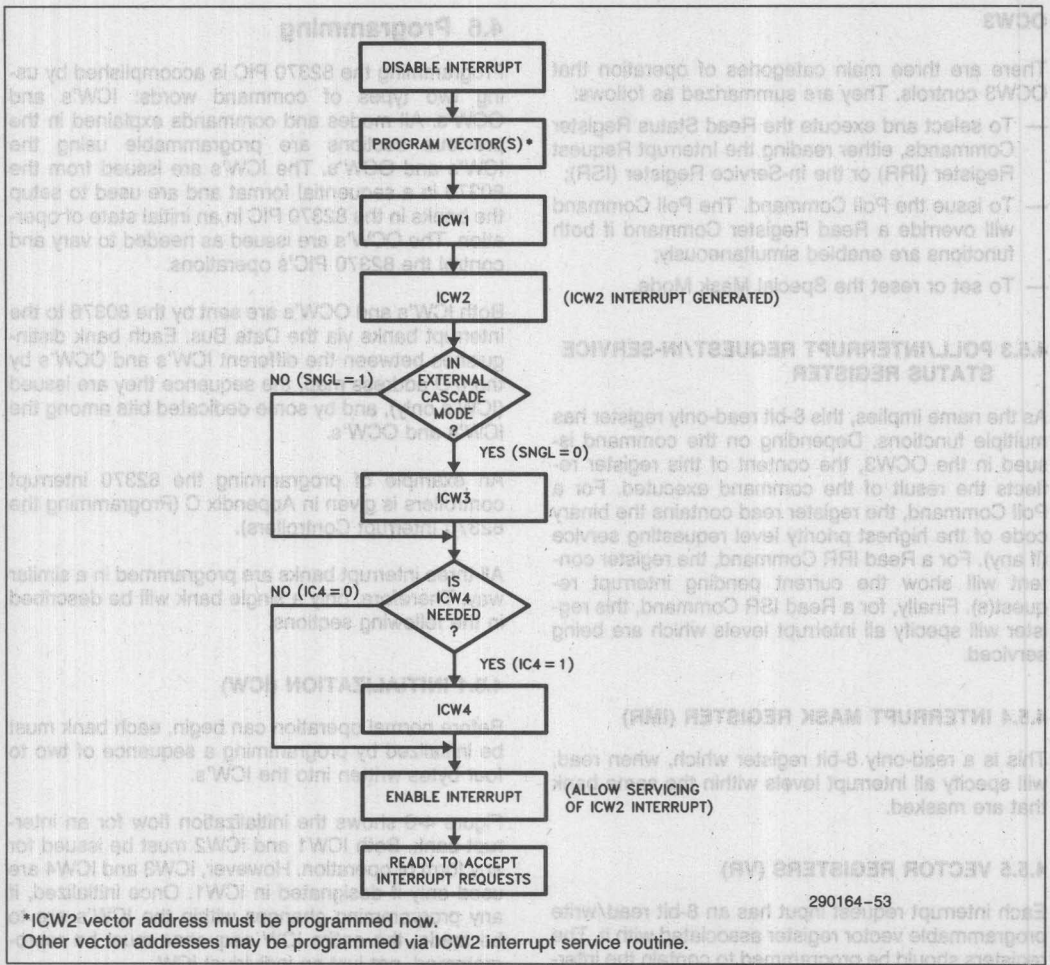


Figure 4-6. Initialization Sequence

Certain internal setup conditions occur automatically within the interrupt bank after the first ICW (ICW1) has been issued. These are:

— The edge sensitive circuit is reset, which means that following initialization, an interrupt request input must make a HIGH-to-LOW transition to generate an interrupt;

— The Interrupt Mask Register (IMR) is cleared; that is, all interrupt inputs are enabled;

— IRQ7 input of each bank is assigned priority 7 (lowest);

— Special Mask Mode is cleared and Status Read is set to IRR;

— If no ICW4 is needed, then no Automatic-EOI is selected.

4.6.2 VECTOR REGISTERS (VR)

Each interrupt request input has a separate Vector Register. These Vector Registers are used to store the pre-programmed vector number corresponding to their interrupt sources. In order to guarantee proper interrupt handling, all Vector Registers must be programmed with the predefined vector numbers. Since an interrupt request will be generated whenever an ICW2 is written during the initialization sequence, it is important that the Vector Register of IRQ1.5 in Bank A should be initialized and the interrupt service routine of this vector is set up before the ICW's are written.

4.6.3 OPERATION CONTROL WORDS (OCW)

After the ICW's are programmed, the operations of each interrupt controller bank can be changed by writing into the OCW's as explained before. There is no special programming sequence required for the OCW's. Any OCW may be written at any time in order to change the mode of or to perform certain operations on the interrupt banks.

4.6.3.1 Read Status and Poll Commands (OCW3)

Since the reading of IRR and ISR status as well as the result of a Poll Command are available on the same read-only Status Register, a special Read Status/Poll Command must be issued before the Poll/Interrupt Request/In-Service Status Register is read. This command can be specified by writing the required control word into OCW3. As mentioned earlier, if both the Poll Command and the Status Read Command are enabled simultaneously, the Poll Command will override the Status Read. That is, after the command execution, the Status Register will contain the result of the Poll Command.

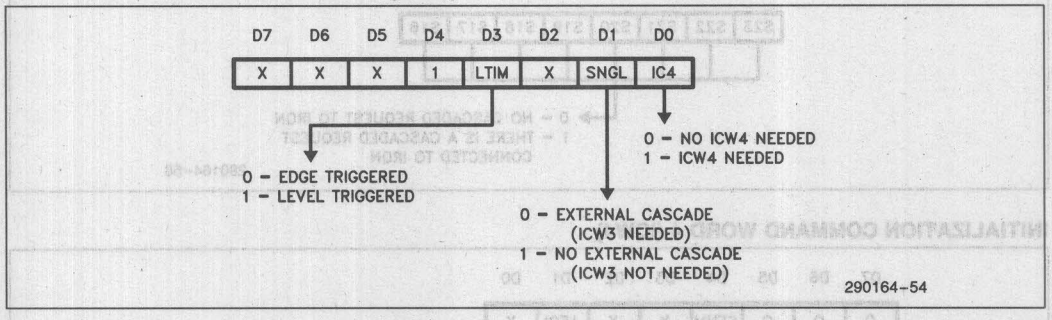
Note that for reading IRR and ISR, there is no need to issue a Read Status Command to the OCW3 every time the IRR or ISR is to be read. Once a Read Status Command is received by the interrupt bank, it "remembers" which register is selected. However, this is not true when the Poll Command is used.

In the Poll Command, after the OCW3 is written, the 82370 PIC treats the next read to the Status Register as an interrupt acknowledge. This will set the appropriate IS bit if there is a request and read the priority level. Interrupt Request input status remains unchanged from the Poll Command to the Status Read.

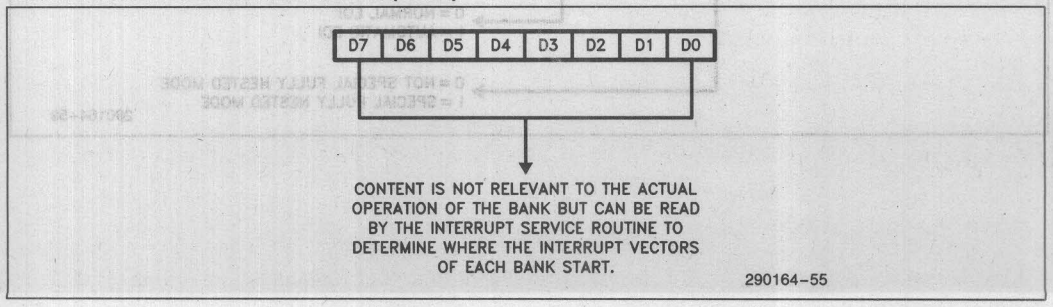
In addition to the above read commands, the Interrupt Mask Register (IMR) can also be read. When read, this register reflects the contents of the preprogrammed OCW1 which contains information on which interrupt request(s) is(are) currently disabled.

4.7 Register Bit Definition

INITIALIZATION COMMAND WORD 1 (ICW1)

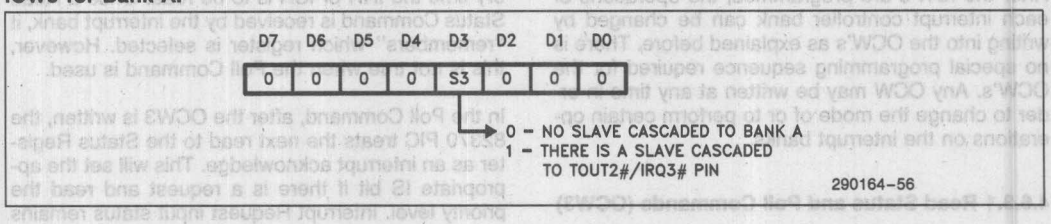


INITIALIZATION COMMAND WORD 2 (ICW2)

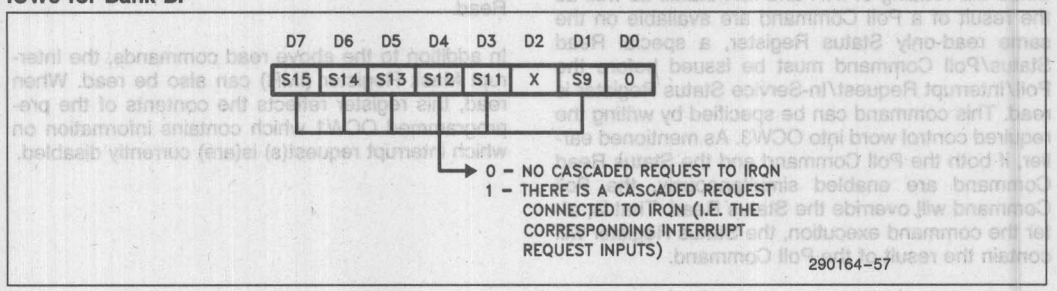


INITIALIZATION COMMAND WORD 3 (ICW3)

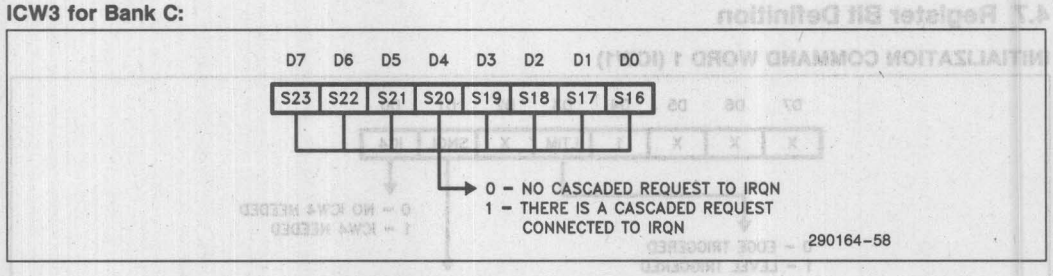
ICW3 for Bank A:



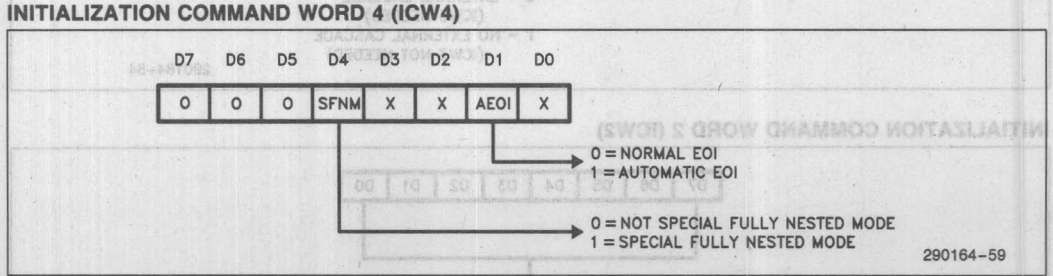
ICW3 for Bank B:



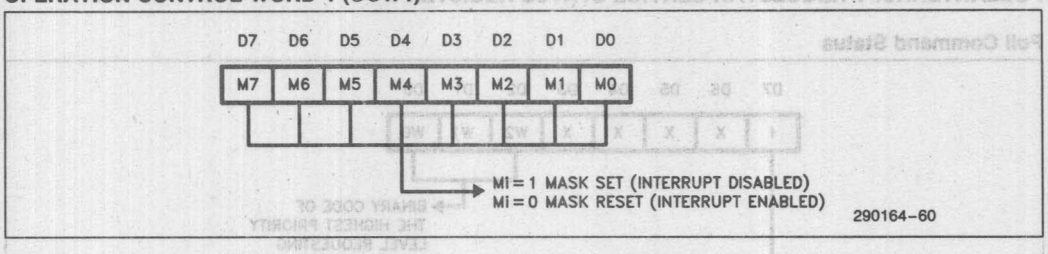
ICW3 for Bank C:



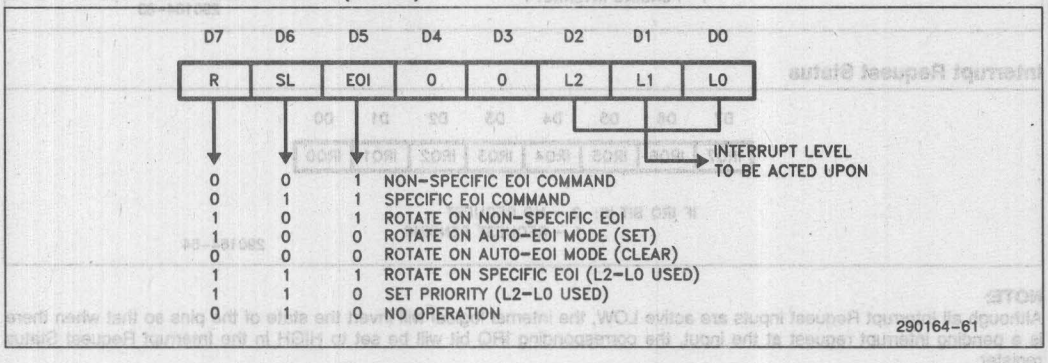
INITIALIZATION COMMAND WORD 4 (ICW4)



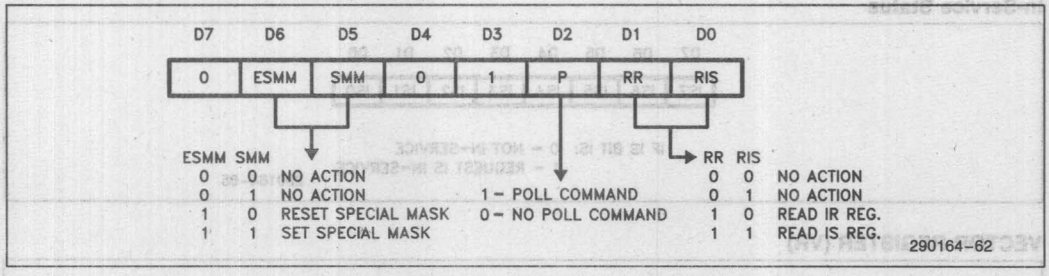
OPERATION CONTROL WORD 1 (OCW1)



OPERATION CONTROL WORD 2 (OCW2)



OPERATION CONTROL WORD 3 (OCW3)



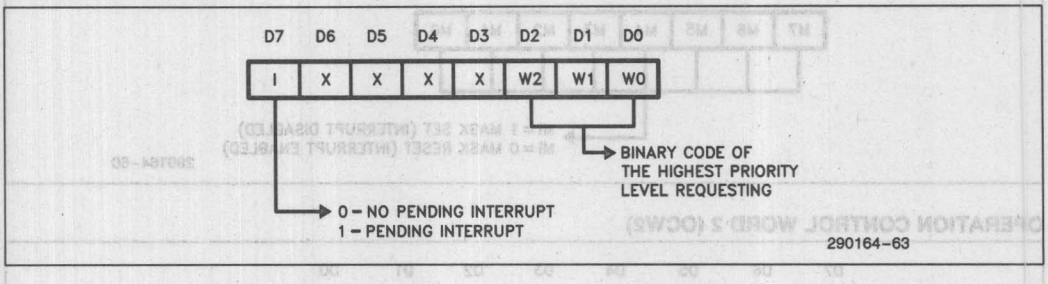
ESMM — Enable Special Mask Mode. When this bit is set to 1, it enables the SMM bit to set or reset the Special Mask Mode. When this bit is set to 0, SMM bit becomes don't care.

SMM — Special Mask Mode. If ESMM = 1 and SMM = 1, the interrupt controller bank will enter Special Mask Mode. If ESMM = 1 and SMM = 0, the bank will revert to normal mask mode. When ESMM = 0, SMM has no effect.

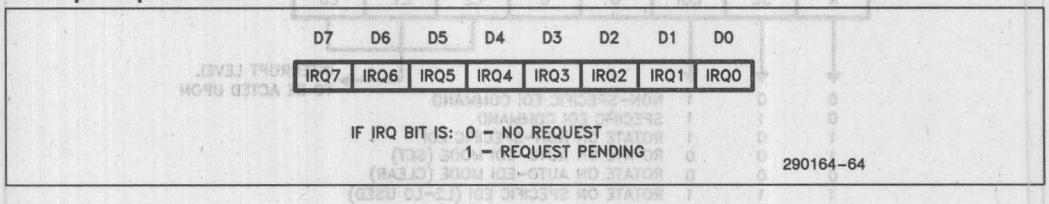
9

POLL/INTERRUPT REQUEST/IN-SERVICE STATUS REGISTER

Poll Command Status

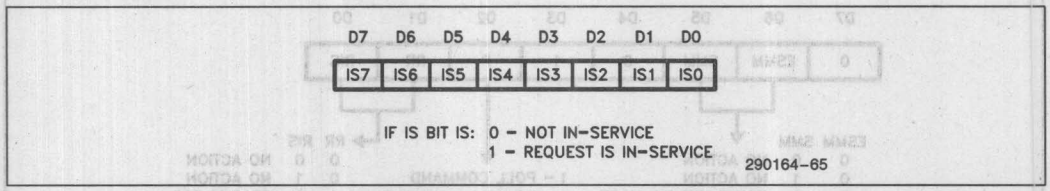


Interrupt Request Status



NOTE:
Although all Interrupt Request inputs are active LOW, the internal logical will invert the state of the pins so that when there is a pending interrupt request at the input, the corresponding IRQ bit will be set to HIGH in the Interrupt Request Status register.

In-Service Status



VECTOR REGISTER (VR)

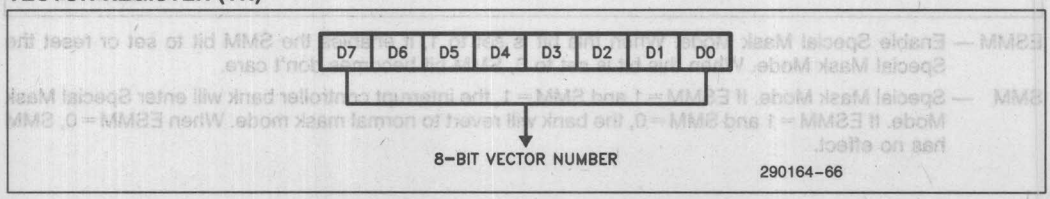


Table 4-4. Register Operational Summary

Operational Description	Command Words	Bits
Fully Nested Mode	OCW-Default	
Non-specific EOI Command	OCW2	EOI
Specific EOI Command	OCW2	SL, EOI, L0–L2
Automatic EOI Mode	ICW1, ICW4	IC4, AEOI
Rotate On Non-Specific EOI Command	OCW2	EOI
Rotate On Automatic EOI Mode	OCW2	R, SL, EOI
Set Priority Command	OCW2	L0–L2
Rotate On Specific EOI Command	OCW2	R, SL, EOI
Interrupt Mask Register	OCW1	M0–M7
Special Mask Mode	OCW3	ESMM, SMM
Level Triggered Mode	ICW1	LTIM
Edge Triggered Mode	ICW1	LTIM
Read Register Command, IRR	OCW3	RR, RIS
Read Register Command, ISR	OCW3	RR, RIS
Read IMR	IMR	M0–M7
Poll Command	OCW3	P
Special Fully Nested Mode	ICW1, ICW4	IC4, SFNM

4.8 Register Operational Summary

For ease of reference, Table 4-4 gives a summary of the different operating modes and commands with their corresponding registers.

5.0 PROGRAMMABLE INTERVAL TIMER

5.1 Functional Description

The 82370 contains four independently Programmable Interval Timers: Timer 0–3. All four timers are functionally compatible to the Intel 82C54. The first three timers (Timer 0–2) have specific functions. The fourth timer, Timer 3, is a general purpose timer. Table 5-1 depicts the functions of each timer. A brief description of each timer's function follows.

Table 5-1. Programmable Interval Timer Functions

Timer	Output	Function
0	IRQ8	Event Based IRQ8 Generator
1	TOUT1/REF#	Gen. Purpose/DRAM Refresh Req.
2	TOUT2/IRQ3#	Gen. Purpose/Speaker Out/IRQ3#
3	TOUT3#	Gen. Purpose/IRQ0 Generator

TIMER 0—Event Based Interrupt Request 8 Generator

Timer 0 is intended to be used as an Event Counter. The output of this timer will generate an Interrupt Request 8 (IRQ8) upon a rising edge of the timer output (TOUT0). Normally, this timer is used to implement a time-of-day clock or system tick. The Timer 0 output is not available as an external signal.

TIMER 1—General Purpose/DRAM Refresh Request

The output of Timer 1, TOUT1, can be used as a general purpose timer or as a DRAM Refresh Request signal. The rising edge of this output creates a DRAM refresh request to the 82370 DRAM Refresh Controller. Upon reset, the Refresh Request function is disabled, and the output pin is the Timer 1 output.

TIMER 2—General Purpose/Speaker Out/IRQ3#

The Timer 2 output, TOUT2#, could be used to support tone generation to an external speaker. This pin is a bidirectional signal. When used as an input, a logic LOW asserted at this pin will generate an Interrupt Request 3 (IRQ3#) (see Programmable Interrupt Controller).

9

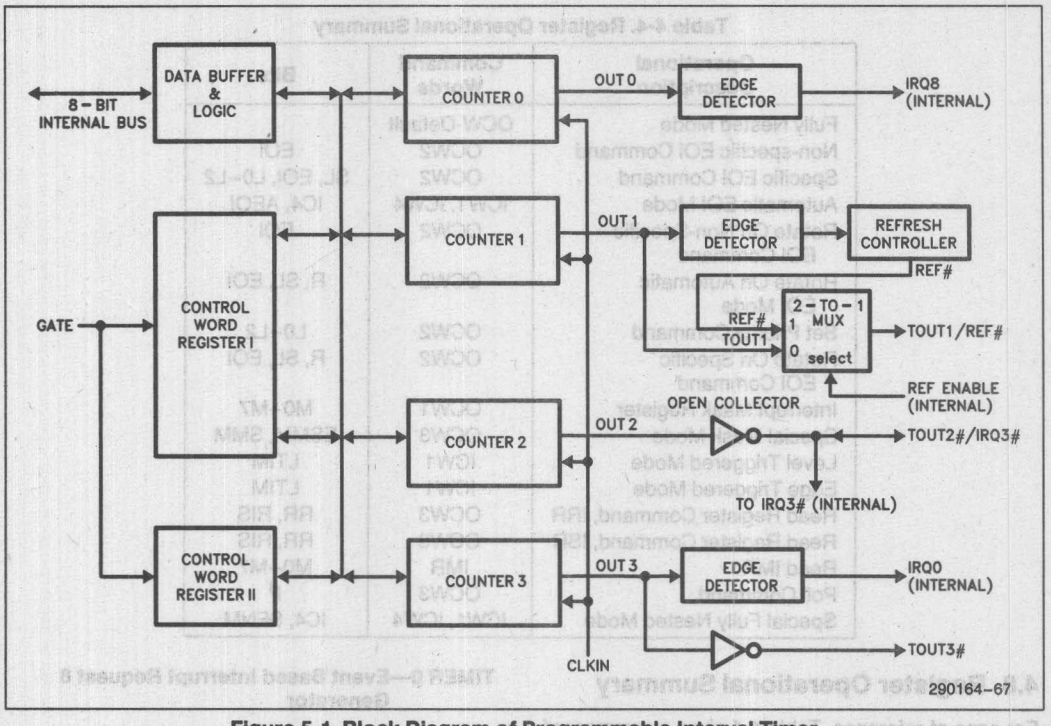


Figure 5-1. Block Diagram of Programmable Interval Timer

TIMER 3—General Purpose/Interrupt Request 0 Generator

The output of Timer 3 is fed to an edge detector and generates an Interrupt Request 0 (IRQ0) in the 82370. The inverted output of this timer (TOUT3#) is also available as an external signal for general purpose use.

5.1.1 INTERNAL ARCHITECTURE

The functional block diagram of the Programmable Interval Timer section is shown in Figure 5-1. Following is a description of each block.

DATA BUFFER & READ/WRITE LOGIC

This part of the Programmable Interval Timer is used to interface the four timers to the 82370 internal bus. The Data Buffer is for transferring commands and data between the 8-bit internal bus and the timers. The Read/Write Logic accepts inputs from the internal bus and generates signals to control other functional blocks within the timer section.

CONTROL WORD REGISTERS I & II

The Control Word Registers are write-only registers. They are used to control the operating modes of the timers. Control Word Register I controls Timers 0, 1 and 2, and Control Word Register II controls Timer 3. Detailed description of the Control Word Registers will be included in the Register Set Overview section.

COUNTER 0, COUNTER 1, COUNTER 2, COUNTER 3

Counters 0, 1, 2, and 3 are the major parts of Timers 0, 1, 2, and 3, respectively. These four functional blocks are identical in operation, so only a single counter will be described. The internal block diagram of one counter is shown in Figure 5-2.

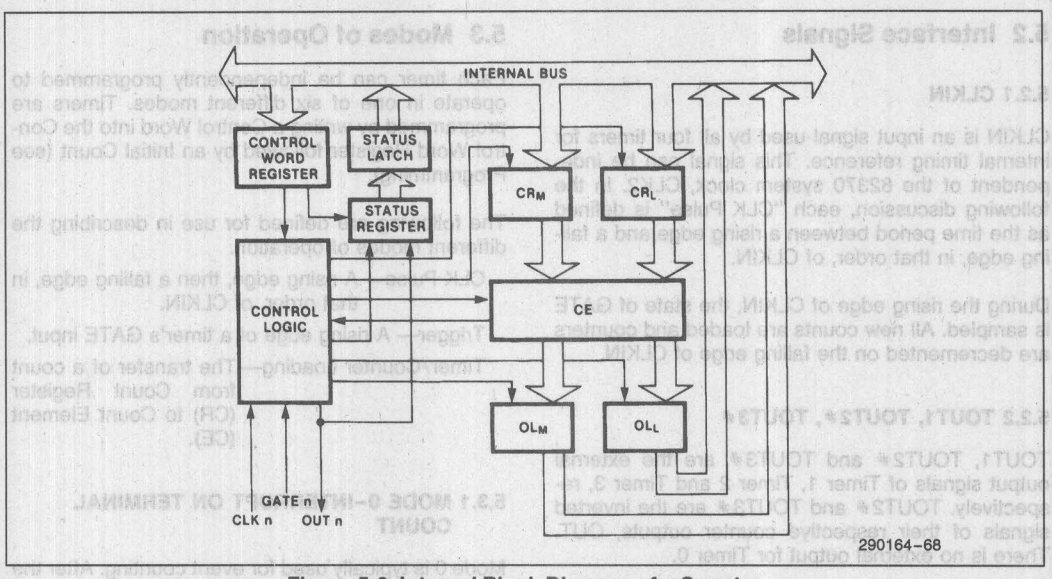


Figure 5-2. Internal Block Diagram of a Counter

The four counters share a common clock input (CLKIN), but otherwise are fully independent. Each counter is programmable to operate in a different mode.

Although the Control Word Register is shown in the figure, it is not part of the counter itself. Its programmed contents are used to control the operations of the counters.

The Status Register, when latched, contains the current contents of the Control Word Register and status of the output and Null Count Flag (see Read Back Command).

The Counting Element (CE) is the actual counter. It is a 16-bit presettable synchronous down counter.

The Output Latches (OL) contain two 8-bit latches (OLM and OLL). Normally, these latches "follow" the content of the CE. OLM contains the most significant byte of the counter and OLL contains the least significant byte. If the Counter Latch Command is sent to the counter, OL will latch the present count until read by the 80376 and then return to follow the CE. One latch at a time is enabled by the timer's Control Logic to drive the internal bus. This is how the 16-bit Counter communicates over the 8-bit internal bus. Note that CE cannot be read. Whenever the count is read, it is one of the OL's that is being read.

When a new count is written into the counter, the value will be stored in the Count Registers (CR), and transferred to CE. The transferring of the contents from CR's to CE is defined as "loading" of the counter. The Count Register contains two 8-bit registers: CRM (which contains the most significant byte) and CRL (which contains the least significant byte). Similar to the OL's, the Control Logic allows one register at a time to be loaded from the 8-bit internal bus. However, both bytes are transferred from the CR's to the CE simultaneously. Both CR's are cleared when the Counter is programmed. This way, if the Counter has been programmed for one byte count (either the most significant or the least significant byte only), the other byte will be zero. Note that CE cannot be written into directly. Whenever a count is written, it is the CR that is being written.

As shown in the diagram, the Control Logic consists of three signals: CLKIN, GATE, and OUT. CLKIN and GATE will be discussed in detail in the section that follows. OUT is the internal output of the counter. The external outputs of some timers (TOUT) are the inverted version of OUT (see TOUT1, TOUT2#, TOUT3#). The state of OUT depends on the mode of operation of the timer.

5.2 Interface Signals

5.2.1 CLKIN

CLKIN is an input signal used by all four timers for internal timing reference. This signal can be independent of the 82370 system clock, CLK2. In the following discussion, each "CLK Pulse" is defined as the time period between a rising edge and a falling edge, in that order, of CLKIN.

During the rising edge of CLKIN, the state of GATE is sampled. All new counts are loaded and counters are decremented on the falling edge of CLKIN.

5.2.2 TOUT1, TOUT2#, TOUT3#

TOUT1, TOUT2# and TOUT3# are the external output signals of Timer 1, Timer 2 and Timer 3, respectively. TOUT2# and TOUT3# are the inverted signals of their respective counter outputs, OUT. There is no external output for Timer 0.

If Timer 2 is to be used as a tone generator of a speaker, external buffering must be used to provide sufficient drive capability.

The Outputs of Timer 2 and 3 are dual function pins. The output pin of Timer 2 (TOUT2#/IRQ3#), which is a bidirectional open-collector signal, can also be used as interrupt request input. When the interrupt function is enabled (through the Programmable Interrupt Controller), a LOW on this input will generate an Interrupt Request 3# to the 82370 Programmable Interrupt Controller. This pin has a weak internal pull-up resistor. To use the IRQ3# function, Timer 2 should be programmed so that OUT2 is LOW. Additionally, OUT3 of Timer 3 is connected to an edge detector which will generate an Interrupt Request 0 (IRQ0) to the 82370 after the rising edge of OUT3 (see Figure 5-1).

5.2.3 GATE

GATE is not an externally controllable signal. Rather, it can be software controlled with the Internal Control Port. The state of GATE is always sampled on the rising edge of CLKIN. Depending on the mode of operation, GATE is used to enable/disable counting or trigger the start of an operation.

For Timer 0 and 1, GATE is always enabled (HIGH). For Timer 2 and 3, GATE is connected to Bit 0 and 6, respectively, of an Internal Control Port (at address 61H) of the 82370. After a hardware reset, the state of GATE of Timer 2 and 3 is disabled (LOW).

5.3 Modes of Operation

Each timer can be independently programmed to operate in one of six different modes. Timers are programmed by writing a Control Word into the Control Word Register followed by an Initial Count (see Programming).

The following are defined for use in describing the different modes of operation.

CLK Pulse— A rising edge, then a falling edge, in that order, of CLKIN.

Trigger— A rising edge of a timer's GATE input.

Timer/Counter Loading— The transfer of a count from Count Register (CR) to Count Element (CE).

5.3.1 MODE 0–INTERRUPT ON TERMINAL COUNT

Mode 0 is typically used for event counting. After the Control Word is written, OUT is initially LOW, and will remain LOW until the counter reaches zero. OUT then goes HIGH and remains HIGH until a new count or a new Mode 0 Control Word is written into the counter.

In this mode, GATE=HIGH enables counting; GATE = LOW disables counting. However, GATE has no effect on OUT.

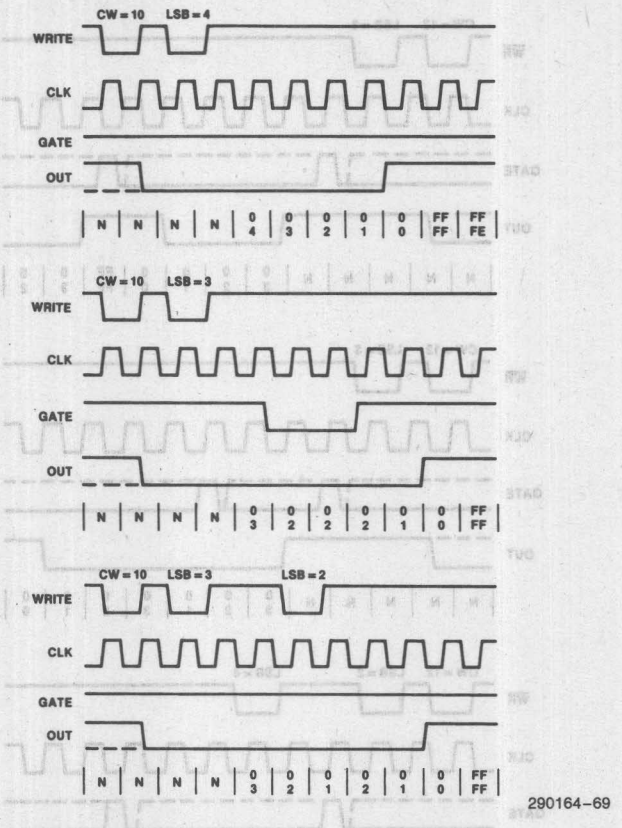
After the Control Word and initial count are written to a timer, the initial count will be loaded on the next CLK pulse. This CLK pulse does not decrement the count, so for an initial count of N, OUT does not go HIGH until N+1 CLK pulses after the initial count is written.

If a new count is written to the timer, it will be loaded on the next CLK pulse and counting will continue from the new count. If a two-byte count is written, the following happens:

1. Writing the first byte disables counting, OUT is set LOW immediately (i.e. no CLK pulse required).

2. Writing the second byte allows the new count to be loaded on the next CLK pulse.

This allows the counting sequence to be synchronized by software. Again, OUT does not go HIGH until N+1 CLK pulses after the new count of N is written.



NOTES:
The following conventions apply to all mode timing diagrams.
1. Counters are programmed for binary (not BCD) counting and for reading/writing least significant byte (LSB) only.
2. The counter is always selected (CS# always low).
3. CW stands for "Control Word"; CW = 10 means a control word of 10, Hex is written to the counter.
4. LSB stands for "Least significant byte" of count.
5. Numbers below diagrams are count values.
The lower number is the least significant byte.
The upper number is the most significant byte. Since the counter is programmed to read/write LSB only, the most significant byte cannot be read.
N stands for an undefined count.
Vertical lines show transitions between count values.

Figure 5-3. Mode 0

If an initial count is written while GATE is LOW, the counter will be loaded on the next CLK pulse. When GATE goes HIGH, OUT will go HIGH N CLK pulses later; no CLK pulse is needed to load the counter as this has already been done.

5.3.2 MODE 1–GATE RETRIGGERABLE *ONE-SHOT*

In this mode, OUT will be initially HIGH. OUT will go LOW on the CLK pulse following a trigger to start the one-shot operation. The OUT signal will then remain LOW until the timer reaches zero. At this point, OUT will stay HIGH until the next trigger comes in. Since the state of GATE signals of Timer 0 and 1 are internally set to HIGH.

After writing the Control Word and initial count, the timer is considered "armed". A trigger results in loading the timer and setting OUT LOW on the next CLK pulse. Therefore, an initial count of N will result in a one-shot pulse width of N CLK cycles. Note

9

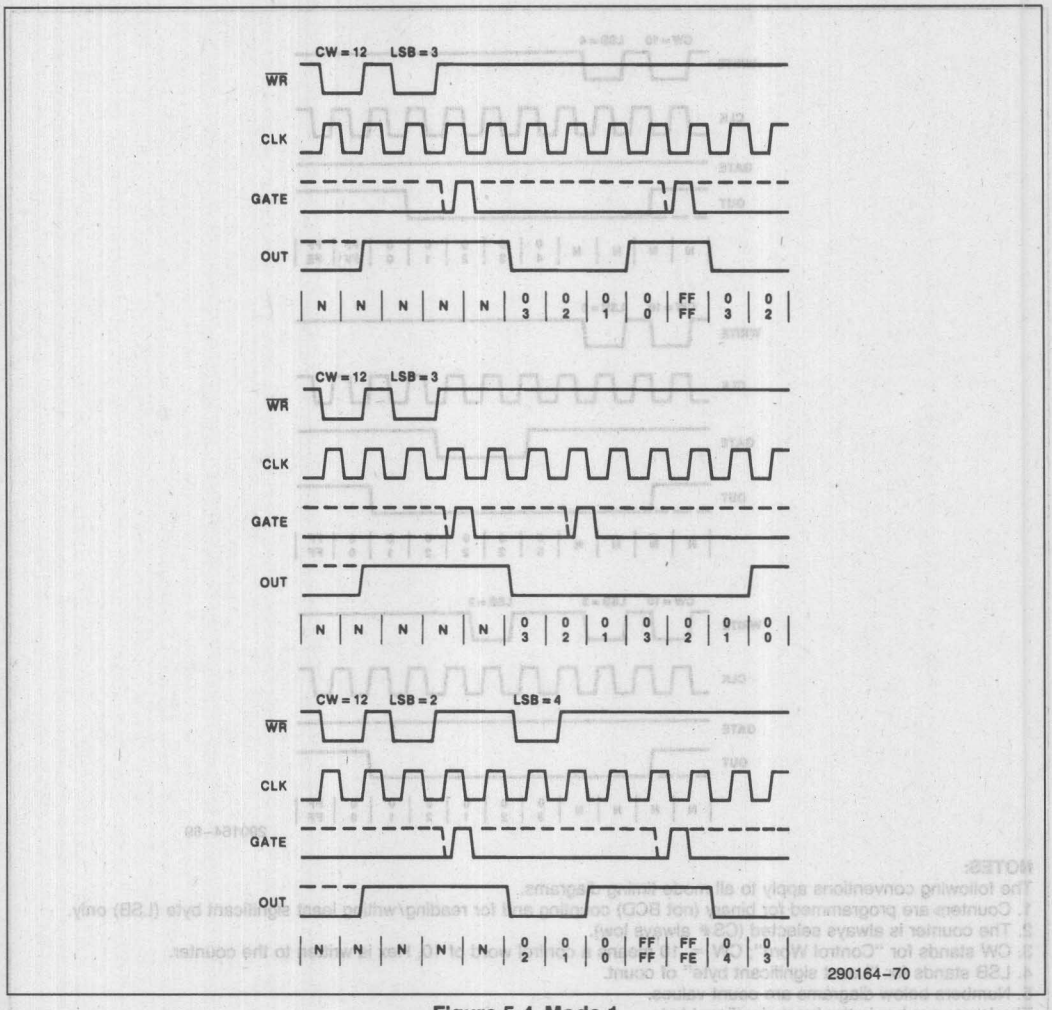


Figure 5-4. Mode 1

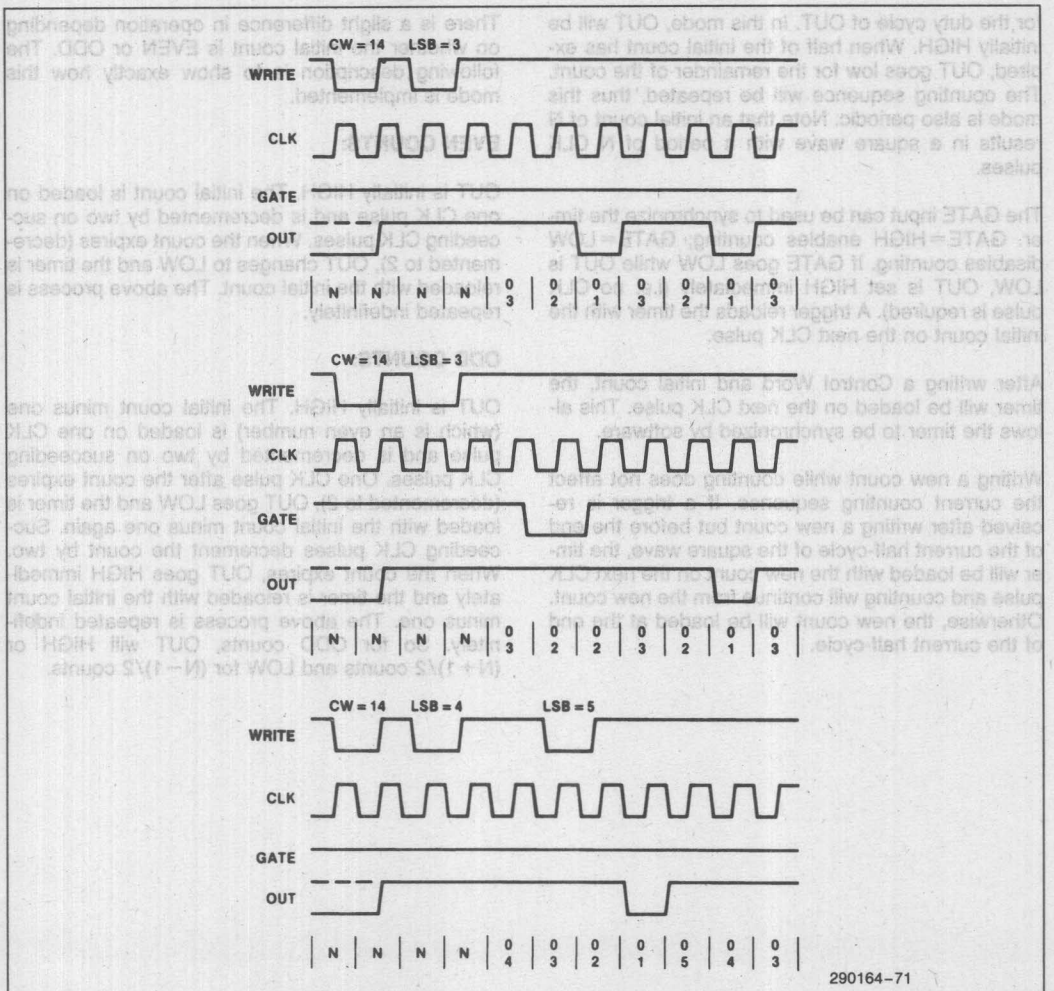
that this one-shot operation is retriggerable; i.e. OUT will remain LOW for N CLK pulses after every trigger. The one-shot operation can be repeated without rewriting the same count into the timer.

If a new count is written to the timer during a one-shot operation, the current one-shot pulse width will not be affected until the timer is retriggered. This is because loading of the new count to CE will occur only when the one-shot is triggered.

5.3.3 MODE 2–RATE GENERATOR

This mode is a divide-by-N counter. It is typically used to generate a Real Time Clock interrupt. OUT will initially be HIGH. When the initial count has decremented to 1, OUT goes LOW for one CLK pulse, then OUT goes HIGH again. Then the timer reloads the initial count and the process is repeated. In other words, this mode is periodic since the same sequence is repeated itself indefinitely. For an initial count of N, the sequence repeats every N CLK cycles.

Similar to Mode 0, GATE = HIGH enables counting, where GATE = LOW disables counting. If GATE goes LOW during an output pulse (LOW), OUT is set HIGH immediately. A trigger (rising edge on GATE) will reload the timer with the initial count on the next CLK pulse. Then, OUT will go LOW (for one CLK pulse) N CLK pulses after the new trigger. Thus, GATE can be used to synchronize the timer.



NOTE:
A GATE transition should not occur one clock prior to terminal count.

Figure 5-5. Mode 2

After writing a Control Word and initial count, the timer will be loaded on the next CLK pulse. OUT goes LOW (for one CLK pulse) N CLK pulses after the initial count is written. This is another way the timer may be synchronized by software.

Writing a new count while counting does not affect the current counting sequence because the new count will not be loaded until the end of the current counting cycle. If a trigger is received after writing a new count but before the end of the current period, the timer will be loaded with the new count on the next CLK pulse after the trigger, and counting will continue with the new count.

5.3.4 MODE 3–SQUARE WAVE GENERATOR

Mode 3 is typically used for Baud Rate generation. Functionally, this mode is similar to Mode 2 except

for the duty cycle of OUT. In this mode, OUT will be initially HIGH. When half of the initial count has expired, OUT goes low for the remainder of the count. The counting sequence will be repeated, thus this mode is also periodic. Note that an initial count of N results in a square wave with a period of N CLK pulses.

The GATE input can be used to synchronize the timer. GATE = HIGH enables counting; GATE = LOW disables counting. If GATE goes LOW while OUT is LOW, OUT is set HIGH immediately (i.e. no CLK pulse is required). A trigger reloads the timer with the initial count on the next CLK pulse.

After writing a Control Word and initial count, the timer will be loaded on the next CLK pulse. This allows the timer to be synchronized by software.

Writing a new count while counting does not affect the current counting sequence. If a trigger is received after writing a new count but before the end of the current half-cycle of the square wave, the timer will be loaded with the new count on the next CLK pulse and counting will continue from the new count. Otherwise, the new count will be loaded at the end of the current half-cycle.

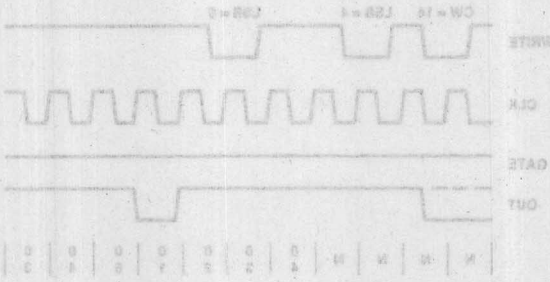
There is a slight difference in operation depending on whether the initial count is EVEN or ODD. The following description is to show exactly how this mode is implemented.

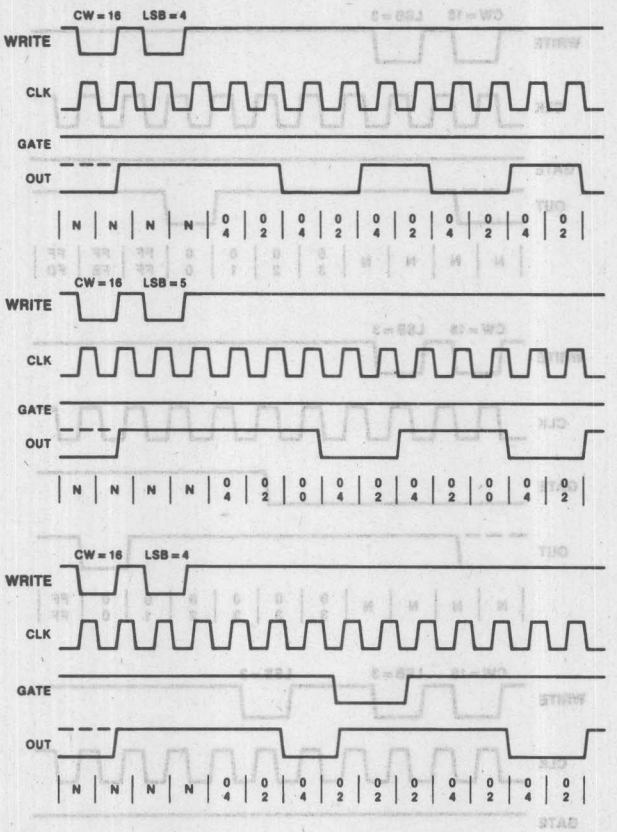
EVEN COUNTS:

OUT is initially HIGH. The initial count is loaded on one CLK pulse and is decremented by two on succeeding CLK pulses. When the count expires (decremented to 2), OUT changes to LOW and the timer is reloaded with the initial count. The above process is repeated indefinitely.

ODD COUNTS:

OUT is initially HIGH. The initial count minus one (which is an even number) is loaded on one CLK pulse and is decremented by two on succeeding CLK pulses. One CLK pulse after the count expires (decremented to 2), OUT goes LOW and the timer is loaded with the initial count minus one again. Succeeding CLK pulses decrement the count by two. When the count expires, OUT goes HIGH immediately and the timer is reloaded with the initial count minus one. The above process is repeated indefinitely. So for ODD counts, OUT will HIGH or (N+1)/2 counts and LOW for (N−1)/2 counts.





NOTE:
A GATE transition should not occur one clock prior to terminal count.

Figure 5-6. Mode 3

5.3.5 MODE 4–INITIAL COUNT TRIGGERED STROBE

This mode allows a strobe pulse to be generated by writing an initial count to the timer. Initially, OUT will be HIGH. When a new initial count is written into the timer, the counting sequence will begin. When the initial count expires (decremented to 1), OUT will go LOW for one CLK pulse and then go HIGH again.

Again, GATE = HIGH enables counting while GATE = LOW disables counting. GATE has no effect on OUT.

After writing the Control Word and initial count, the timer will be loaded on the next CLK pulse. This CLK pulse does not decrement the count, so for an initial count of N, OUT does not strobe LOW until N + 1 CLK pulses after initial count is written.

If a new count is written during counting, it will be loaded in the next CLK pulse and counting will continue from the new count.

9

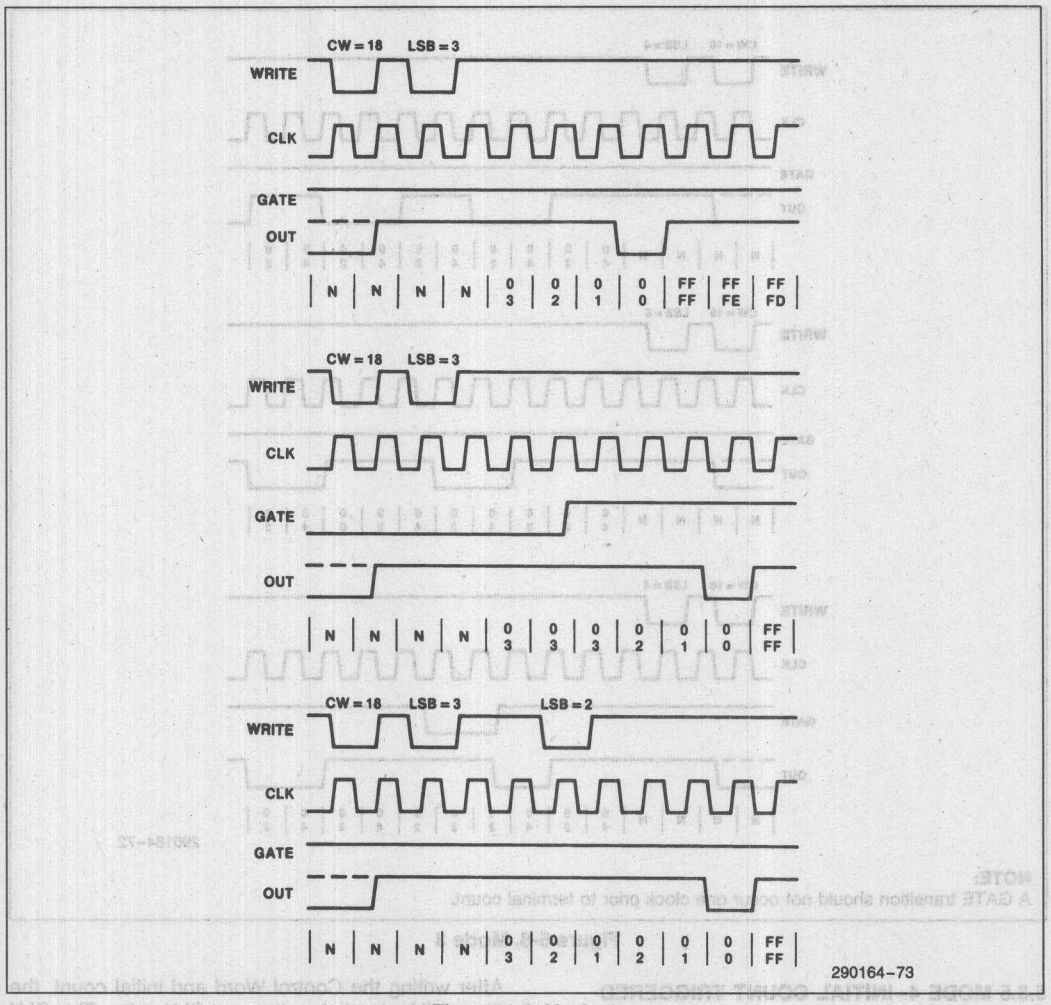


Figure 5-7. Mode 4

If a two-byte count is written, the following will occur:

1. Writing the first byte has no effect on counting.

2. Writing the second byte allows the new count to be loaded on the next CLK pulse.

OUT will strobe LOW N+1 CLK pulses after the new count of N is written. Therefore, when the strobe pulse will occur after a trigger depends on the value of the initial count loaded.

5.3.6 MODE 5–GATE RETRIGGERABLE STROBE

Mode 5 is very similar to Mode 4 except the count sequence is triggered by the gate signal instead of by writing an initial count. Initially, OUT will be HIGH. Counting is triggered by a rising edge of GATE. When the initial count has expired (decremented to 1), OUT will go LOW for one CLK pulse and then go HIGH again.

After loading the Control Word and initial count, the Count Element will not be loaded until the CLK pulse after a trigger. This CLK pulse does not decrement the count. Therefore, for an initial count of N, OUT does not strobe LOW until N+1 CLK pulses after a trigger.

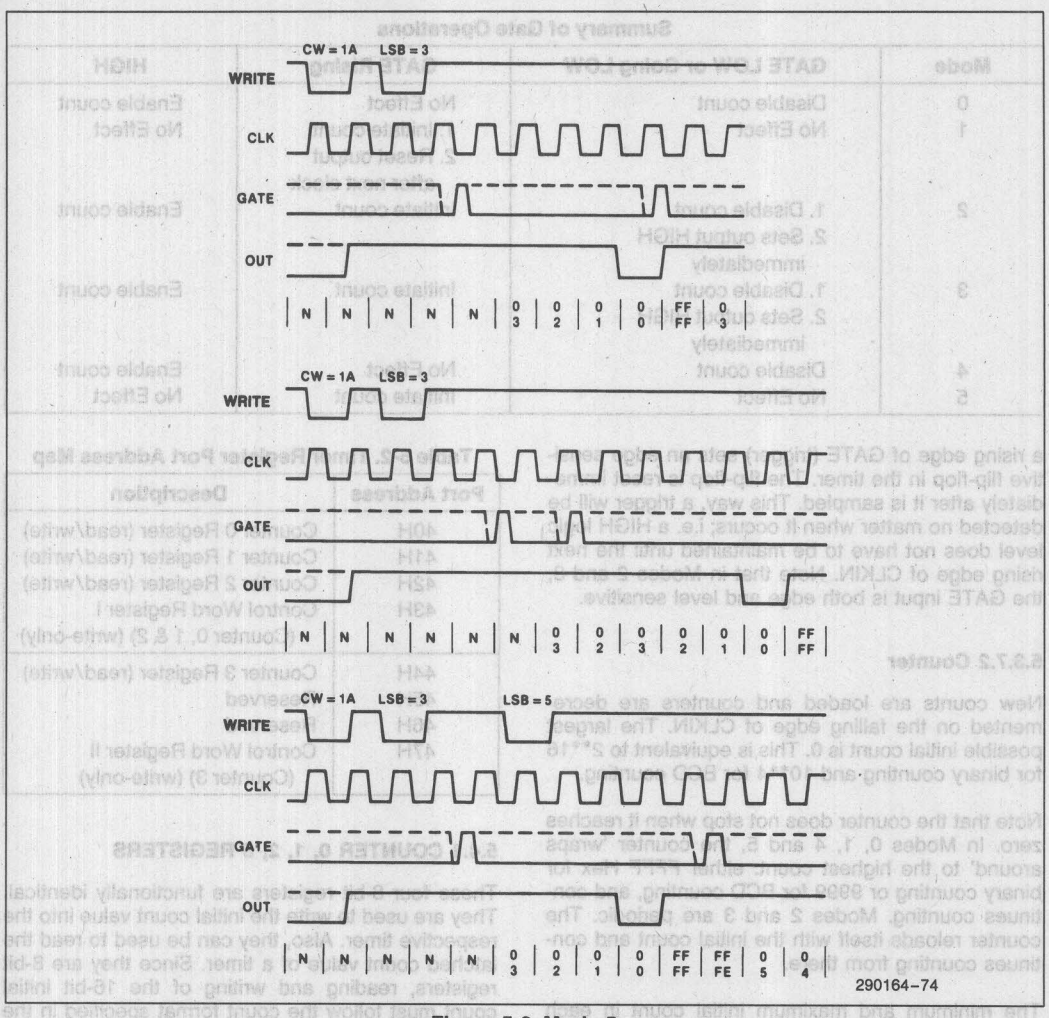


Figure 5-8. Mode 5

The counting sequence is retriggerable. Every trigger will result in the timer being loaded with the initial count on the next CLK pulse.

If the new count is written during counting, the current counting sequence will not be affected. If a trigger occurs after the new count is written but before the current count expires, the timer will be loaded with the new count on the next CLK pulse and a new count sequence will start from there.

5.3.7 OPERATION COMMON TO ALL MODES

5.3.7.1 GATE

The GATE input is always sampled on the rising edge of CLKIN. In Modes 0, 2, 3 and 4, the GATE input is level sensitive. The logic level is sampled on the rising edge of CLKIN. In Modes 1, 2, 3 and 5, the GATE input is rising edge sensitive. In these modes,

9

Summary of Gate Operations

Mode	GATE LOW or Going LOW	GATE Rising	HIGH
0	Disable count	No Effect	Enable count
1	No Effect	1. Initiate count 2. Reset output after next clock	No Effect
2	1. Disable count 2. Sets output HIGH immediately	Initiate count	Enable count
3	1. Disable count 2. Sets output HIGH immediately	Initiate count	Enable count
4	Disable count	No Effect	Enable count
5	No Effect	Initiate count	No Effect

a rising edge of GATE (trigger) sets an edge sensitive flip-flop in the timer. The flip-flop is reset immediately after it is sampled. This way, a trigger will be detected no matter when it occurs; i.e. a HIGH logic level does not have to be maintained until the next rising edge of CLKIN. Note that in Modes 2 and 3, the GATE input is both edge and level sensitive.

5.3.7.2 Counter

New counts are loaded and counters are decremented on the falling edge of CLKIN. The largest possible initial count is 0. This is equivalent to 2**16 for binary counting and 10**4 for BCD counting.

Note that the counter does not stop when it reaches zero. In Modes 0, 1, 4 and 5, the counter 'wraps around' to the highest count: either FFFF Hex for binary counting or 9999 for BCD counting, and continues counting. Modes 2 and 3 are periodic. The counter reloads itself with the initial count and continues counting from there.

The minimum and maximum initial count in each counter depends on the mode of operation. They are summarized below.

Mode	Min	Max
0	1	0
1	1	0
2	2	0
3	2	0
4	1	0
5	1	0

5.4 Register Set Overview

The Programmable Interval Timer module of the 82370 contains a set of six registers. The port address map of these registers is shown in Table 5-2.

Table 5-2. Timer Register Port Address Map

Port Address	Description
40H	Counter 0 Register (read/write)
41H	Counter 1 Register (read/write)
42H	Counter 2 Register (read/write)
43H	Control Word Register I (Counter 0, 1 & 2) (write-only)
44H	Counter 3 Register (read/write)
45H	Reserved
46H	Reserved
47H	Control Word Register II (Counter 3) (write-only)

5.4.1 COUNTER 0, 1, 2, 3 REGISTERS

These four 8-bit registers are functionally identical. They are used to write the initial count value into the respective timer. Also, they can be used to read the latched count value of a timer. Since they are 8-bit registers, reading and writing of the 16-bit initial count must follow the count format specified in the Control Word Registers; i.e. least significant byte only, most significant byte only, or least significant byte then most significant byte (see Programming).

5.4.2 CONTROL WORD REGISTER I & II

There are two Control Word Registers associated with the Timer section. One of the two registers (Control Word Register I) is used to control the operations of Counters 0, 1 and 2 and the other (Control Word Register II) is for Counter 3. The major functions of both Control Word Registers are listed below:

— Select the timer to be programmed.
— Define which mode the selected timer is to operate in.
— Define the count sequence; i.e. if the selected timer is to count as a Binary Counter or a Binary Coded Decimal (BCD) Counter.
— Select the byte access sequence during timer read/write operations; i.e. least significant byte only, most significant only, or least significant byte first, then most significant byte.

Also, the Control Word Registers can be programmed to perform a Counter Latch Command or a Read Back Command which will be described later.

5.5 Programming

5.5.1 INITIALIZATION

Upon power-up or reset, the state of all timers is undefined. The mode, count value, and output of all timers are random. From this point on, how each timer operates is determined solely by how it is programmed. Each timer must be programmed before it can be used. Since the outputs of some timers can generate interrupt signals to the 82370, all timers should be initialized to a known state.

Counters are programmed by writing a Control Word into their respective Control Word Registers. Then, an Initial Count can be written into the corresponding Count Register. In general, the programming procedure is very flexible. Only two conventions need to be remembered:

1. For each timer, the Control Word must be written before the initial count is written.

2. The 16-bit initial count must follow the count format specified in the Control Word (least significant byte only, most significant byte only, or least significant byte first, followed by most significant byte).

Since the two Control Word Registers and the four Counter Registers have separate addresses, and each timer can be individually selected by the appropriate Control Word Register, no special instruction sequence is required. Any programming sequence that follows the conventions above is acceptable.

A new initial count may be written to a timer at any time without affecting the timer's programmed mode in any way. Count sequence will be affected as described in the Modes of Operation section. Note that the new count must follow the programmed count format.

If a timer is previously programmed to read/write two-byte counts, the following precaution applies. A program must not transfer control between writing the first and second byte to another routine which also writes into the same timer. Otherwise, the read/write will result in incorrect count.

Whenever a Control Word is written to a timer, all control logic for that timer(s) is immediately reset (i.e. no CLK pulse is required). Also, the corresponding output in, TOUT#, goes to a known initial state.

5.5.2 READ OPERATION

Three methods are available to read the current count as well as the status of each timer. They are: Read Counter Registers, Counter Latch Command and Read Back Command. Below is a description of these methods.

READ COUNTER REGISTERS

The current count of a timer can be read by performing a read operation on the corresponding Counter Register. The only restriction of this read operation is that the CLKIN of the timers must be inhibited by using external logic. Otherwise, the count may be in the process of changing when it is read, giving an undefined result. Note that since all four timers are sharing the same CLKIN signal, inhibiting CLKIN to read a timer will unavoidably disable the other timers also. This may prove to be impractical. Therefore, it is suggested that either the Counter Latch Command or the Read Back Command can be used to read the current count of a timer.

Another alternative is to temporarily disable a timer before reading its Counter Register by using the GATE input. Depending on the mode of operation, GATE = LOW will disable the counting operation. However, this option is available on Timer 2 and 3 only, since the GATE signals of the other two timers are internally enabled all the time.

COUNTER LATCH COMMAND

A Counter Latch Command will be executed whenever a special Control Word is written into a Control Word Register. Two bits written into the Control Word Register distinguish this command from a 'regular' Control Word (see Register Bit Definition). Also, two other bits in the Control Word will select which counter is to be latched.

Upon execution of this command, the selected counter's Output Latch (OL) latches the count at the time the Counter Latch Command is received. This

count is held in the latch until it is read by the 80376, or until the timer is reprogrammed. The count is then unlatched automatically and the OL returns to "following" the Counting Element (CE). This allows reading the contents of the counters "on the fly" without affecting counting in progress. Multiple Counter Latch Commands may be used to latch more than one counter. Each latched count is held until it is read. Counter Latch Commands do not affect the programmed mode of the timer in any way.

If a counter is latched, and at some time later, it is latched again before the prior latched count is read, the second Counter Latch Command is ignored. The count read will then be the count at the time the first command was issued.

In any event, the latched count must be read according to the programmed format. Specifically, if the timer is programmed for two-byte counts, two bytes must be read. However, the two bytes do not have to be read right after the other. Read/write or programming operations of other timers may be performed between them.

Another feature of this Counter Latch Command is that read and write operations of the same timer may be interleaved. For example, if the timer is programmed for two-byte counts, the following sequence is valid.

1. Read least significant byte.
2. Write new least significant byte.
3. Read most significant byte.
4. Write new most significant byte.

If a timer is programmed to read/write two-byte counts, the following precaution applies. A program must not transfer control between reading the first and second byte to another routine which also reads from that same timer. Otherwise, an incorrect count will be read.

READ BACK COMMAND

The Read Back Command is another special Command Word operation which allows the user to read the current count value and/or the status of the selected timer(s). Like the Counter Latch Command, two bits in the Command Word identify this as a Read Back Command (see Register Bit Definition).

The Read Back Command may be used to latch multiple counter Output Latches (OL's) by selecting more than one timer within a Command Word. This single command is functionally equivalent to several *Counter Latch Commands, one for each counter to* be latched. Each counter's latched count will be held until it is read by the 80376 or until the timer is reprogrammed. The counter is automatically unlatched when read, but other counters remain latched until they are read. If multiple Read Back commands are issued to the same timer without reading the count, all but the first are ignored; i.e. the count read will correspond to the very first Read Back Command issued.

As mentioned previously, the Read Back Command may also be used to latch status information of the selected timer(s). When this function is enabled, the status of a timer can be read from the Counter Register after the Read Back Command is issued. The status information of a timer includes the following:

1. Mode of timer:

   This allows the user to check the mode of operation of the timer last programmed.

2. State of TOUT pin of the timer:

   This allows the user to monitor the counter's output pin via software, possibly eliminating some hardware from a system.

3. Null Count/Count available:

   The Null Count Bit in the status byte indicates if the last count written to the Count Register (CR) has been loaded into the Counting Element (CE). The exact time this happens depends on the mode of the timer and is described in the Programming section. Until the count is loaded into the Counting Element (CE), it cannot be read from the timer. If the count is latched or read before this occurs, the count value will not reflect the new count just written.

If multiple status latch operations of the timer(s) are performed without reading the status, all but the first command are ignored; i.e. the status read in will correspond to the first Read Back Command issued.

Both the current count and status of the selected timer(s) may be latched simultaneously by enabling both functions in a single Read Back Command. This is functionally the same as issuing two separate Read Back Commands at once. Once again, if multiple read commands are issued to latch both the count and status of a timer, all but the first command will be ignored.

If both count and status of a timer are latched, the first read operation of that timer will return the latched status, regardless of which was latched first. The next one or two (if two count bytes are to be read) read operations return the latched count. Note that subsequent read operations on the Counter Register will return the unlatched count (like the first read method discussed).

5.6 Register Bit Definitions

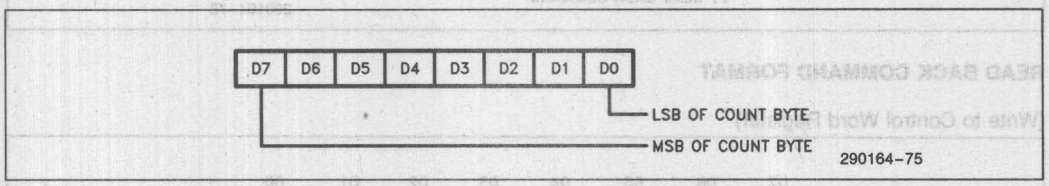
COUNTER 0, 1, 2, 3 REGISTER (READ/WRITE)

Port Address	Description
40H	Counter 0 Register (read/write)
41H	Counter 1 Register (read/write)
42H	Counter 2 Register (read/write)
44H	Counter 3 Register (read/write)
45H	Reserved
46H	Reserved

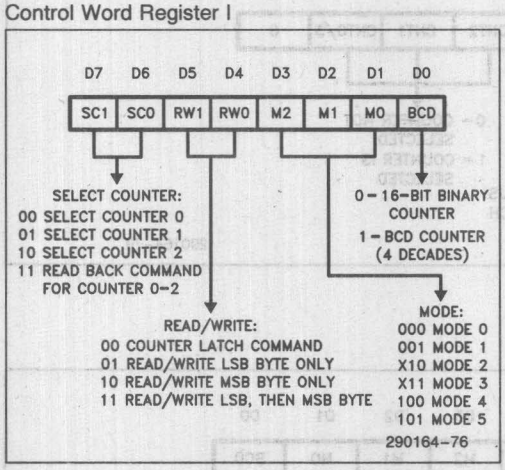
Note that these 8-bit registers are for writing and reading of one byte of the 16-bit count value, either the most significant or the least significant byte.

CONTROL WORD REGISTER I & II (WRITE-ONLY)

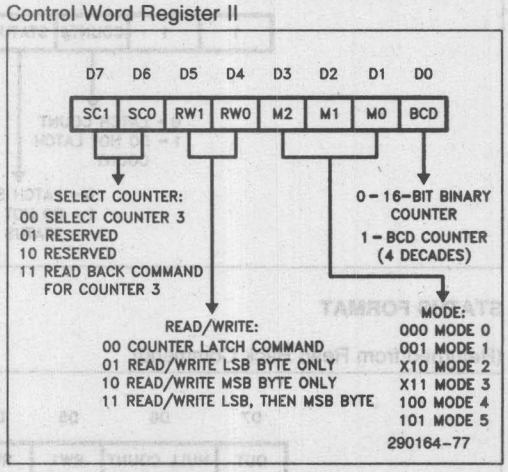
Port Address	Description
43H	Control Word Register I (Counter 0, 1, 2 (write-only)
47H	Control Word Register II (Counter 3) (write-only)



Control Word Register I



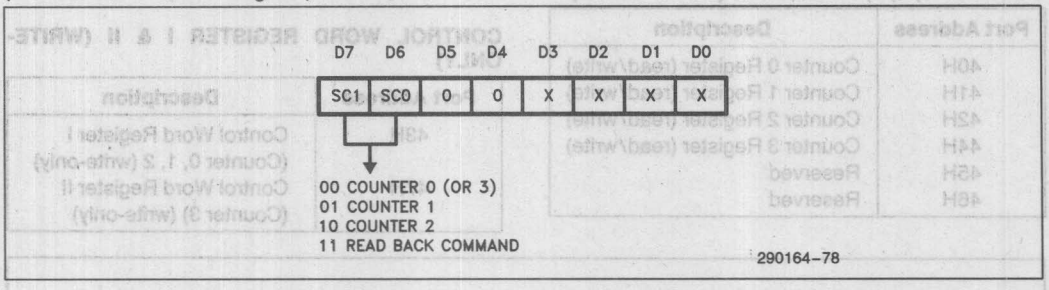
Control Word Register II



9

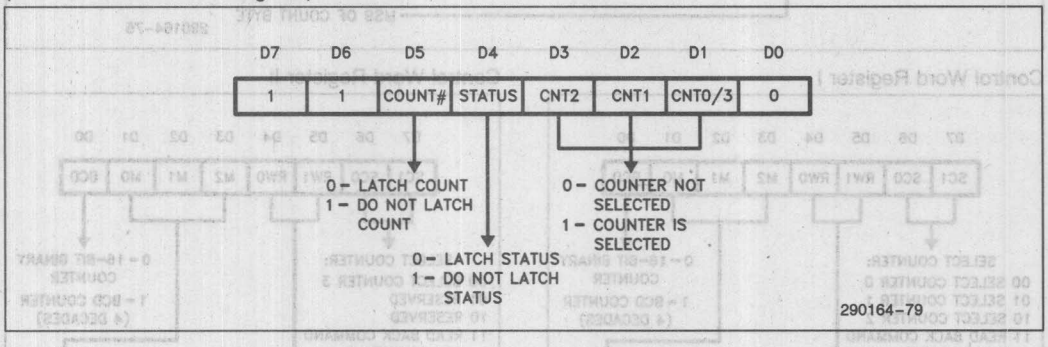
COUNTER LATCH COMMAND FORMAT

(Write to Control Word Register)



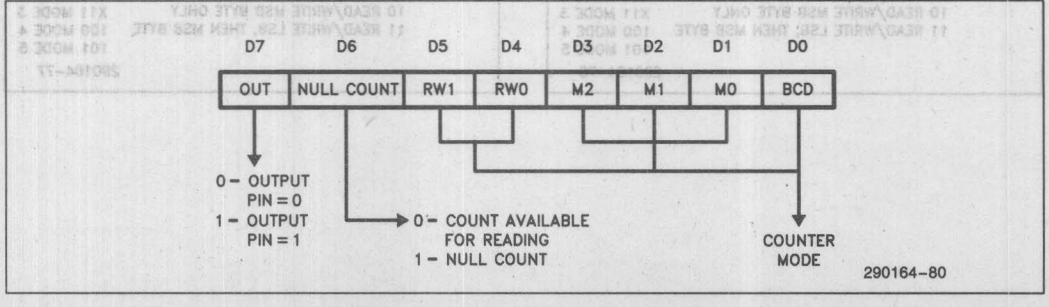
READ BACK COMMAND FORMAT

(Write to Control Word Register)



STATUS FORMAT

(Returned from Read Back Command)



6.0 WAIT STATE GENERATOR

6.1 Functional Description

The 82370 contains a programmable Wait State Generator which can generate a pre-programmed number of wait states during both CPU and DMA initiated bus cycles. This Wait State Generator is capable of generating 1 to 16 wait states in non-pipelined mode, and 0 to 15 wait states in pipelined mode. Depending on the bus cycle type and the two Wait State Control inputs (WSC 0–1), a pre-programmed number of wait states in the selected Wait State Register will be generated.

The Wait State Generator can also be disabled to allow the use of devices capable of generating their own READY# signals. Figure 6-1 is a block diagram of the Wait State Generator.

6.2 Interface Signals

The following describes the interface signals which affect the operation of the Wait State Generator. The READY#, WSC0 and WSC1 signals are inputs. READYO# is the ready output signal to the host processor.

6.2.1 READY#

READY# is an active LOW input signal which indicates to the 82370 the completion of a bus cycle. In the Master mode (e.g. 82370 initiated DMA transfer), this signal is monitored to determine whether a peripheral or memory needs wait states inserted in the current bus cycle. In the Slave mode, it is used (together with the ADS# signal) to trace CPU bus cycles to determine if the current cycle is pipelined.

6.2.2 READYO#

READYO# (Ready Out#) is an active LOW output signal and is the output of the Wait State Generator. The number of wait states generated depends on the WSC(0–1) inputs. Note that special cases are handled for access to the 82370 internal registers and for the Refresh cycles. For 82370 internal register access, READYO# will be delayed to take into the command recovery time of the register. One or more wait states will be generated in a pipelined cycle. During refresh, the number of wait states will be determined by the preprogrammed value in the Refresh Wait State Register.

In the simplest configuration, READYO# can be connected to the READY# input of the 82370 and the 80376 CPU. This is, however, not always the case. If external circuitry is to control the READY# inputs as well, additional logic will be required (see Application Issues).

6.2.3 WSC(0–1)

These two Wait State Control inputs, together with the M/IO# input, select one of the three pre-programmed 8-bit Wait State Registers which determines the number of wait states to be generated. The most significant half of the three Wait State Registers corresponds to memory accesses, the least significant half to I/O accesses. The combination WSC(0–1) = 11 disables the Wait State Generator.

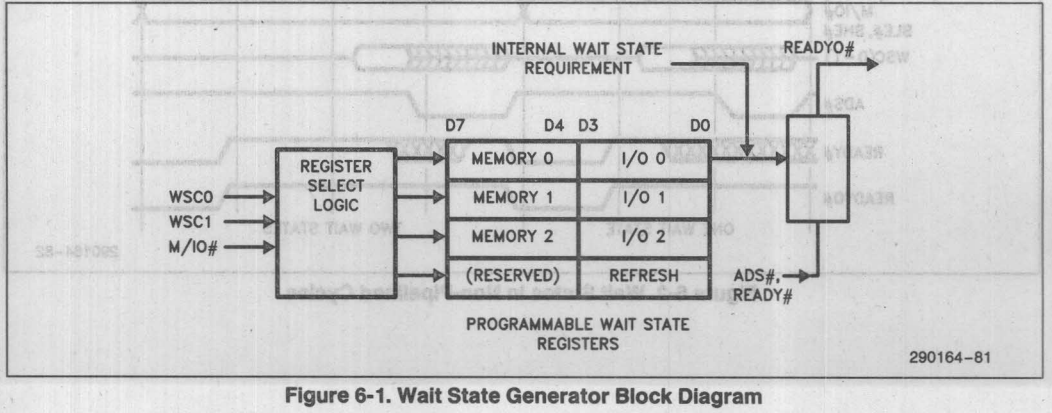


Figure 6-1. Wait State Generator Block Diagram

6.3 Bus Function

6.3.1 WAIT STATES IN NON-PIPELINED CYCLE

The timing diagram of two typical non-pipelined cycles with 82370 generated wait states is shown in Figure 6-2. In this diagram, it is assumed that the internal registers of the 82370 are not addressed. During the first T2 state of each bus cycle, the Wait State Control and the M/IO# inputs are sampled to determine which Wait State Register (if any) is selected. If the WSC inputs are active (i.e. not both are driven HIGH), the pre-programmed number of wait states corresponding to the selected Wait State Register will be requested. This is done by driving the READYO# output HIGH during the end of each T2 state.

The WSC (0–1) inputs need only be valid during the very first T2 state of each non-pipelined cycle. As a general rule, the WSC inputs are sampled on the rising edge of the next clock (82384 CLK) after the last state when ADS# (Address Status) is asserted.

The number of wait states generated depends on the type of bus cycle, and the number of wait states requested. The various combinations are discussed below.

1. Access the 82370 internal registers: 2 to 5 wait states, depending upon the specific register addressed. Some back-to-back sequences to the Interrupt Controller will require 7 wait states.

2. Interrupt Acknowledge to the 82370: 5 wait states.

3. Refresh: As programmed in the Refresh Wait State Register (see Register Set Overview). Note that if WCS (0–1) = 11, READYO# will stay inactive.

4. Other bus cycles: Depending on WCS (0–1) and M/IO# inputs, these inputs select a Wait State Register in which the number of wait states will be equal to the pre-programmed wait state count in the register plus 1. The Wait State Register selection is defined as follows (Table 6-1).

Table 6-1. Wait State Register Selection

M/IO#	WSC(0–1)	Register Selected
0	00	WAIT REG 0 (I/O half)
0	01	WAIT REG 1 (I/O half)
0	10	WAIT REG 2 (I/O half)
1	00	WAIT REG 0 (MEM half)
1	01	WAIT REG 1 (MEM half)
1	10	WAIT REG 2 (MEM half)
X	11	Wait State Gen. Disabled

The Wait State Control signals, WSC (0–1), can be generated with the address decode and the Read/Write control signals as shown in Figure 6-3.

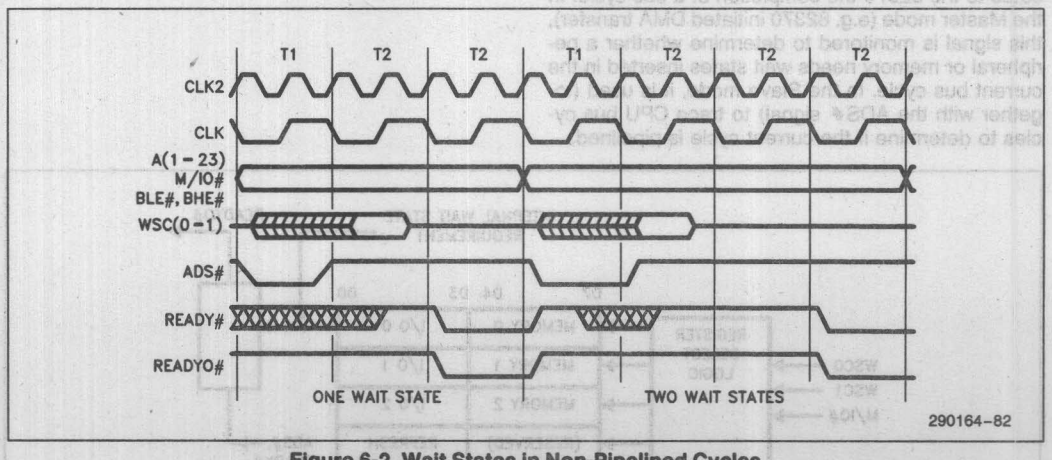


Figure 6-2. Wait States in Non-Pipelined Cycles

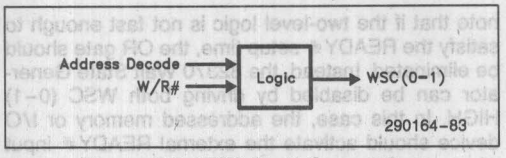


Figure 6-3. WSC (0–1) Generation

Note that during HALT and SHUTDOWN, the number of wait states will depend on the WSC (0–1) inputs, which will select the memory half of one of the Wait State Registers (see CPU Reset and Shutdown Detect).

6.3.2 WAIT STATES IN PIPELINED CYCLES

The timing diagram of two typical pipelined cycles with 82370 generated wait states is shown in Figure 6-4. Again, in this diagram, it is assumed that the 82370 internal registers are not addressed. As defined in the timing of the 80376 processor, the Address (A1–23), Byte Enable (BHE#, BLE#), and other control signals (M/IO#, ADS#) are asserted one T-state earlier than in a non-pipelined cycle; i.e. they are asserted at T2P. Similar to the non-pipelined case, the Wait State Control (WSC) inputs are sampled in the middle of the state after the last state the ADS# signal is asserted. Therefore, the WSC inputs should be asserted during the T1P state of each pipelined cycle (which is one T-state earlier than in the non-pipelined cycle).

The number of wait states generated in a pipelined cycle is selected in a similar manner as in the non-pipelined case discussed in the previous section. The only difference here is that the actual number of wait states generated will be one less than that of the non-pipelined cycle. This is done automatically by the Wait State Generator.

6.3.3 EXTENDING AND EARLY TERMINATING BUS CYCLE

The 82370 allows external logic to either add wait states or cause early termination of a bus cycle by controlling the READY# input to the 82370 and the host processor. A possible configuration is shown in Figure 6-5.

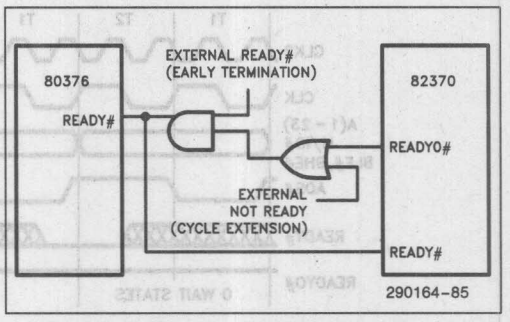


Figure 6-5. External 'READY' Control Logic

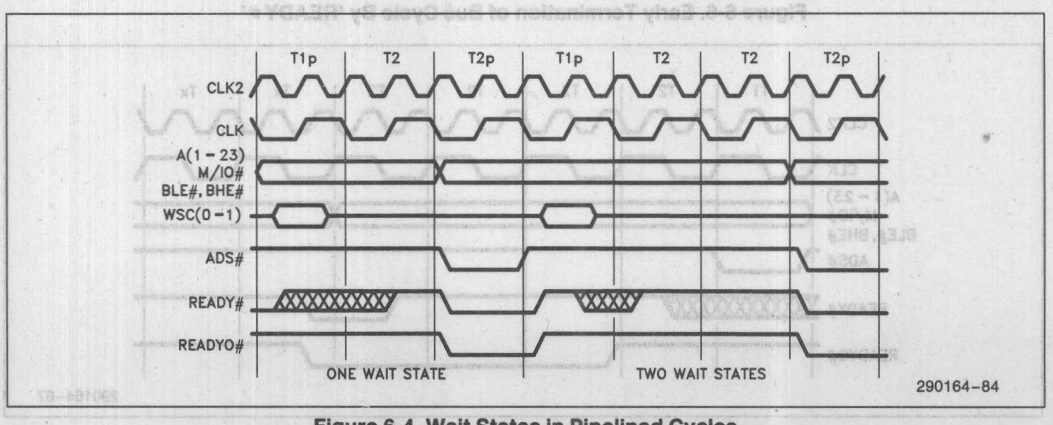


Figure 6-4. Wait States in Pipelined Cycles

9

The EXT. RDY# (External Ready) signal of Figure 6-5 allows external devices to cause early termination of a bus cycle. When this signal is asserted LOW, the output of the circuit will also go LOW (even though the READYO# of the 82370 may still be HIGH). This output is fed to the READY# input of the 80376 and the 82370 to indicate the completion of the current bus cycle.

Similarly, the EXT. NOT READY (External Not Ready) signal is used to delay the READY# input of the processor and the 82370. As long as this signal is driven HIGH, the output of the circuit will drive the READY# input HIGH. This will effectively extend the duration of a bus cycle. However, it is important to note that if the two-level logic is not fast enough to satisfy the READY# setup time, the OR gate should be eliminated. Instead, the 82370 Wait State Generator can be disabled by driving both WSC (0–1) HIGH. In this case, the addressed memory or I/O device should activate the external READY# input whenever it is ready to terminate the current bus cycle.

Figures 6-6 and 6-7 show the timing relationships of the ready signals for the early termination and extension of the bus cycles. Section 6-7, Application Issues, contains a detailed timing analysis of the external circuit.

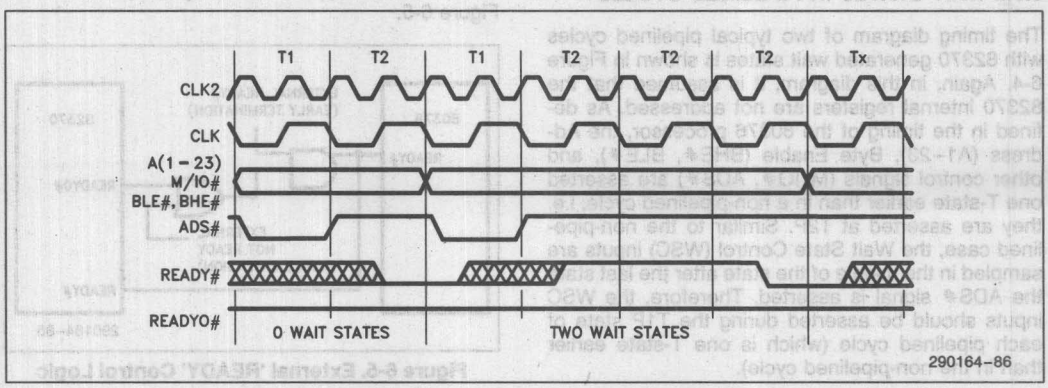


Figure 6-6. Early Termination of Bus Cycle By 'READY#'

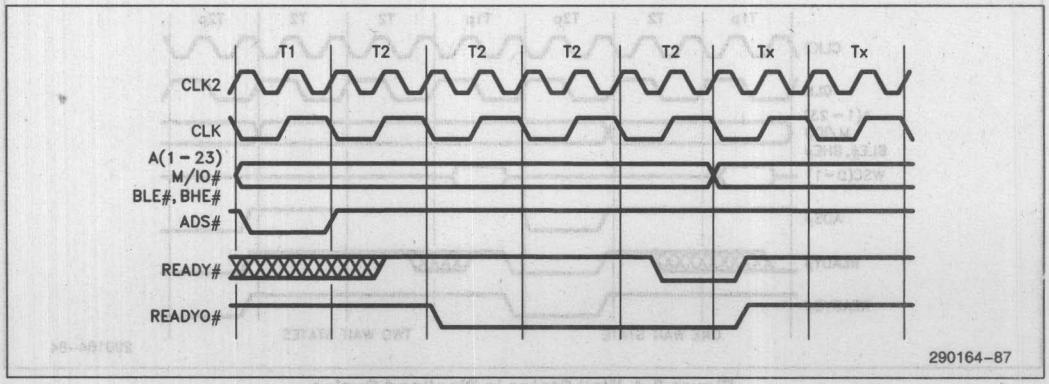


Figure 6-7. Extending Bus Cycle by 'READY#'

Due to the following implications, it should be noted that early termination of bus cycles in which 82370 internal registers are accessed is not recommended.

1. Erroneous data may be read from or written into the addressed register.

2. The 82370 must be allowed to recover either before HLDA (Hold Acknowledge) is asserted or before another bus cycle into an 82370 internal register is initiated.

The recovery time, in clock periods, equals the remaining wait states that were avoided plus 4.

6.4 Register Set Overview

Altogether, there are four 8-bit internal registers associated with the Wait State Genertor. The port address map of these registers is shown below in Table 6-2. A detailed description of each follows.

Table 6-2. Register Address Map

Port Address	Description
72H	Wait State Reg 0 (read/write)
73H	Wait State Reg 1 (read/write)
74H	Wait State Reg 2 (read/write)
75H	Ref. Wait State Reg (read/write)

WAIT STATE REGISTER 0, 1, 2

These three 8-bit read/write registers are functionally identical. They are used to store the pre-programmed wait state count. One half of each register contains the wait state count for I/O accesses while the other half contains the count for memory accesses. The total number of wait states generated will depend on the type of bus cycle. For a non-pipelined cycle, the actual number of wait states requested is equal to the wait state count plus 1. For a pipelined cycle, the number of wait states will be equal to the wait state count in the selected register. Therefore, the Wait State Generator is capable of generating 1 to 16 wait states in non-pipelined mode, and 0 to 15 wait states in pipelined mode.

Note that the minimum wait state count in each register is 0. This is equivalent to 0 wait states for a pipelined cycle and 1 wait state for a non-pipelined cycle.

REFRESH WAIT STATE REGISTER

Similar to the Wait State Registers discussed above, this 4-bit register is used to store the number of wait states to be generated during a DRAM refresh cycle.

Note that the Refresh Wait State Register is not selected by the WSC inputs. It will automatically be chosen whenever a DRAM refresh cycle occurs. If the Wait State Generator is disabled during the refresh cycle (WSC (0–1) = 11), READYO# will stay inactive and the Refresh Wait State Register is ignored.

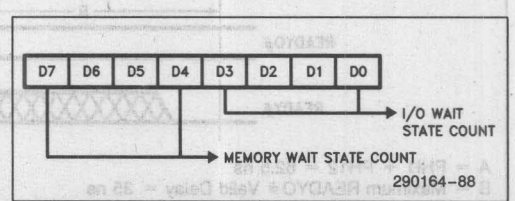
6.5 Programming

Using the Wait State Generator is relatively straightforward. No special programming sequence is required. In order to ensure the expected number of wait states will be generated when a register is selected, the registers to be used must be programmed after power-up by writing the appropriate wait state count into each register. Note that upon hardware reset, all Wait State Registers are initialized with the value FFH, giving the maximum number of wait states possible. Also, each register can be read to check the wait state count previously stored in the register.

6.6 Register Bit Definition

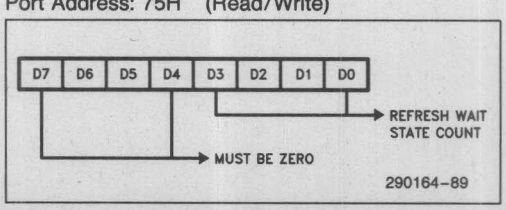
WAIT STATE REGISTER 0, 1, 2

Port Address	Description
72H	Wait State Register 0 (read/write)
73H	Wait State Register 1 (read/write)
74H	Wait State Register 2 (read/write)



REFRESH WAIT STATE REGISTER

Port Address: 75H (Read/Write)



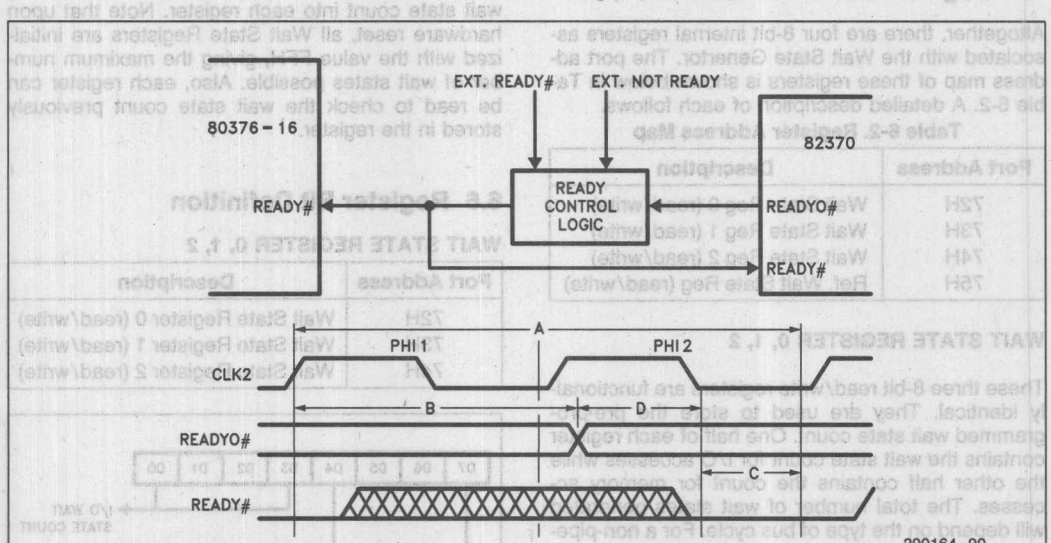
6.7 Application Issues

6.7.1 EXTERNAL 'READY' CONTROL LOGIC

As mentioned in section 6.3.3, wait state cycles generated by the 82370 can be terminated early or extended longer by means of additional external logic (see Figure 6-5). In order to ensure that the READY# input timing requirement of the 80376 and the 82370 is satisfied, special care must be taken when designing this external control logic. This section addresses the design requirements.

A simplified block diagram of the external logic along with the READY# timing diagram is shown in Figure 6-8. The purpose is to determine the maximum delay time allowed in the external control logic in order to satisfy the READY# setup time.

First, it will be assumed that the 80376 is running at 16 MHz (i.e. CLK2 is 32 MHz). Therefore, one bus state (two CLK2 periods) will be equivalent to 62.5 ns. According to the AC specifications of the 82370, the maximum delay time for valid READYO# signal is 31 ns after the rising edge of CLK2 in the beginning of T2 (for non-pipelined cycle) or T2P (for pipelined cycle). Also, the minimum READY# setup time of the 80376 and the 82370 should be 19 ns before the rising edge of CLK2 at the beginning of the next bus state. This limits the total delay time for the external READY# control logic to be 12.5 ns (62.5–31–19) in order to meet the READY# setup timing requirement.



A = PHI1 + PH12 = 62.5 ns
B = Maximum READYO# Valid Delay = 35 ns
C = READY# Setup Time = 20 ns
D = Maximum Ready Control Logic Delay = A - B - C = 7.5 ns

Figure 6-8. 'READY' Timing Consideration

7.0 DRAM REFRESH CONTROLLER

7.1 Functional Description

The 82370 DRAM Refresh Controller consists of a 24-bit Refresh Address Counter and Refresh Request logic for DRAM refresh operations (see Figure 7-1). TIMER 1 can be used as a trigger signal to the DRAM Refresh Request logic. The Refresh Bus Size can be programmed to be 8- or 16-bit wide. Depending on the Refresh Bus Size, the Refresh Address Counter will be incremented with the appropriate value after every refresh cycle. The internal logic of the 82370 will give the Refresh operation the highest priority in the bus control arbitration process. Bus control is not released and re-requested if the 82370 is already a bus master.

7.2 Interface Signals

7.2.1 TOUT1/REF#

The dual function output pin of TIMER 1 (TOUT1/REF#) can be programmed to generate DRAM Refresh signal. If this feature is enabled, the rising edge of TIMER 1 output (TOUT1#) will trigger the DRAM Refresh Request logic. After some delay for gaining access of the bus, the 82370 DRAM Controller will generate a DRAM Refresh signal by driving REF# output LOW. This signal is cleared after the refresh cycle has taken place, or by a hardware reset.

If the DRAM Refresh feature is disabled, the TOUT1/REF# output pin is simply the TIMER 1 output. Detailed information of how TIMER 1 operates is discussed in section 6—Programmable Interval Timer, and will not be repeated here.

7.3 Bus Function

7.3.1 ARBITRATION

In order to ensure data integrity of the DRAMs, the 82370 gives the DRAM Refresh signal the highest priority in the arbitration logic. It allows DRAM Refresh to interrupt DMA in progress in order to perform the DRAM Refresh cycle. The DMA service will be resumed after the refresh is done.

In case of a DRAM Refresh during a DMA process, the cascaded device will be requested to get off the bus. This is done by de-asserting the EDACK signal. Once DREQn goes inactive, the 82370 will perform the refresh operation. Note that the DMA controller does not completely relinquish the system bus during refresh. The Refresh Generator simply "steals" a bus cycle between DMA accesses.

Figure 7-2 shows the timing diagram of a Refresh Cycle. Upon expiration of TIMER 1, the 82370 will try to take control of the system bus by asserting HOLD. As soon as the 82370 see HLDA go active, the DRAM Refresh Cycle will be carried out by activating the REF# signal as well as the address and control signals on the system bus (Note that REF# will not be active until two CLK periods HLDA is asserted). The address bus will contain the 24-bit ad-

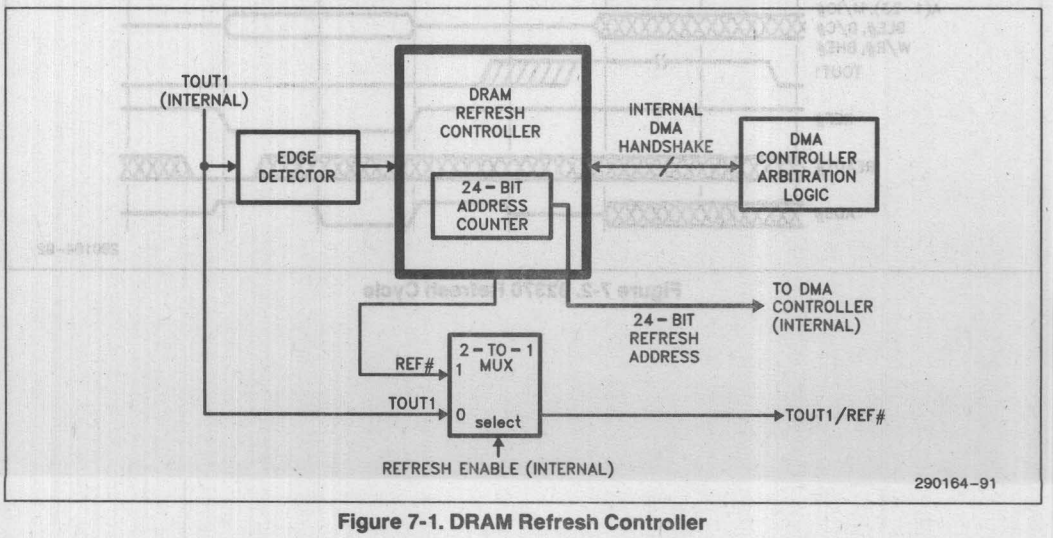


Figure 7-1. DRAM Refresh Controller

dress currently in the Refresh Address Counter. The control signals are driven the same way as in a Memory Read cycle. This "read" operation is complete when the READY# signal is driven LOW. Then, the 82370 will relinquish the bus by de-asserting HOLD. Typically, a Refresh Cycle without wait states will take five bus states to execute. If "n" wait states are added, the Refresh Cycle will last for five plus "n" bus states.

How often the Refresh Generator will initiate a refresh cycle depends on the frequency of CLKIN as will as TIMER 1's programmed mode of operation. For this specific application, TIMER 1 should be programmed to operate in Mode 2 to generate a constant clock rate. See section 6—Programmable Interval Timer for more information on programming the timer. One DRAM Refresh Cycle will be generated each time TIMER 1 expires (when TOUT1 changes from LOW to HIGH).

The Wait State Generator can be used to insert wait states during a refresh cycle. The 82370 will automatically insert the desired number of wait states as programmed in the Refresh Wait State Register (see Wait State Generator).

7.4 Modes of Operation

7.4.1 WORD SIZE AND REFRESH ADDRESS COUNTER

The 82370 supports 8- and 16-bit refresh cycle. The bus width during a refresh cycle is programmable (see Programming). The bus size can be programmed via the Refresh Control Register (see Register Overview). If the DRAM bus size is 8- or 16-bits, the Refresh Address Counter will be incremented by 1 or 2, respectively.

The Refresh Address Counter is cleared by a hardware reset.

7.5 Register Set Overview

The Refresh Generator has two internal registers to control its operation. They are the Refresh Control Register and the Refresh Wait State Register. Their port address map is shown in Table 7-1 below.

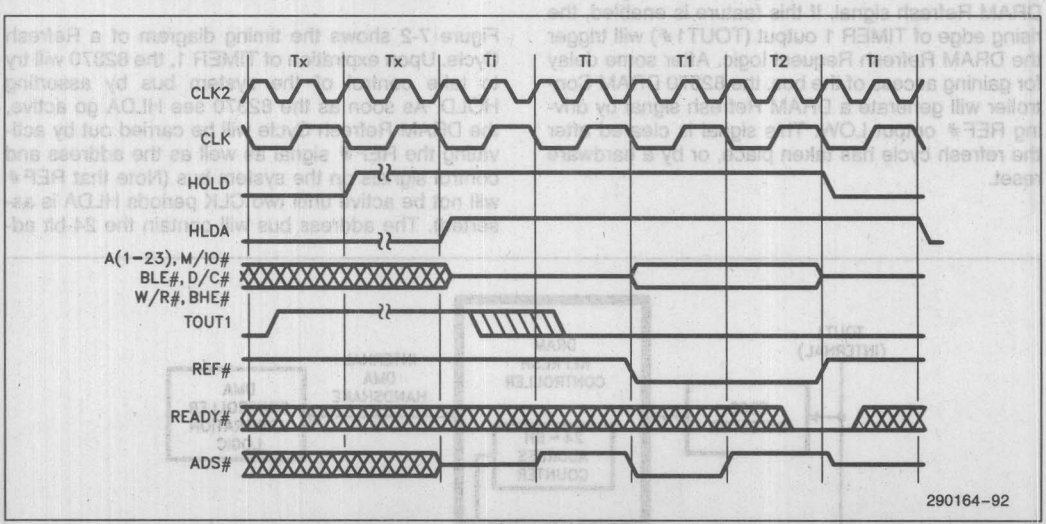


Figure 7-2. 82370 Refresh Cycle

Table 7-1. Register Address Map

Port Address	Description
1CH	Refresh Control Reg. (read/write)
75H	Ref. Wait State Reg. (read/write)

The Refresh Wait State Register is not part of the Refresh Generator. It is only used to program the number of wait states to be inserted during a refresh cycle. This register is discussed in detailed in section 7 (Wait State Generator) and will not be repeated here.

REFRESH CONTROL REGISTER

This 2-bit register serves two functions. First, it is used to enable/disable the DRAM Refresh function output. If disabled, the output of TIMER 1 is simply used as a general purpose timer. The second function of this register is to program the DRAM bus size for the refresh operation. The programmed bus size also determines how the Refresh Address Counter will be incremented after each refresh operation.

7.6 Programming

Upon hardware reset, the DRAM Refresh function is disabled (the Refresh Control Register is cleared). The following programming steps are needed before the Refresh Generator can be used. Since the rate of refresh cycles depends on how TIMER 1 is programmed, this timer must be initialized with the desired mode of operation as well as the correct refresh interval (see Programming Interval Timer). Whether or not wait states are to be generated during a refresh cycle, the Refresh Wait State Register must also be programmed with the appropriate value. Then, the DRAM Refresh feature must be enabled and the DRAM bus width should be defined. These can be done in one step by writing the appropriate control word into the Refresh Control Register (see Register Bit Definition). After these steps are done, the refresh operation will automatically be invoked by the Refresh Generator upon expiration of Timer 1.

In addition to the above programming steps, it should be noted that after reset, although the TOUT1/REF# becomes the Time 1 output, the state of this pin in undefined. This is because the Timer module has not been initialized yet. Therefore, if this output is used as a DRAM Refresh signal, this pin should be disqualified by external logic until the Refresh function is enabled. One simple solution is to logically AND this output with HLDA, since HLDA should not be active after reset.

7.7 Register Bit Definition

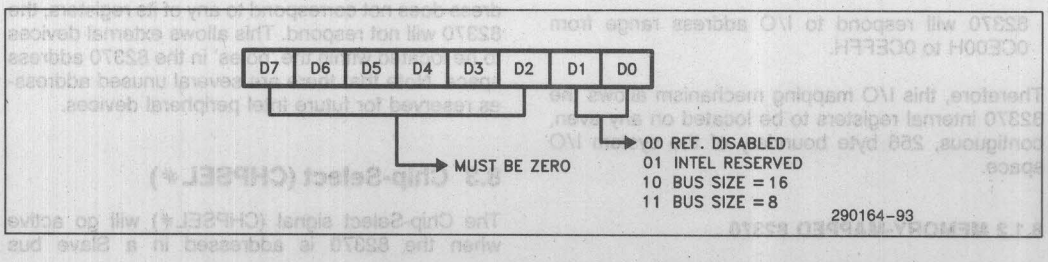
REFRESH CONTROL REGISTER

Port Address: 1CH (Read/Write)

8.0 RELOCATION REGISTER, ADDRESS DECODE, AND CHIP-SELECT (CHPSEL#)

8.1 Relocation Register

All the integrated peripheral devices in the 82370 are controlled by a set of internal registers. These registers span a total of 256 consecutive address locations (although not all the 256 locations are used). The 82370 provides a Relocation Register which allows the user to map this set of internal registers into either the memory or I/O address space. The function of the Relocation Register is to define the base address of the internal register set of the 82370 as well as if the registers are to be memory- or I/O-mapped. The format of the Relocation Register is depicted in Figure 8-1.



9

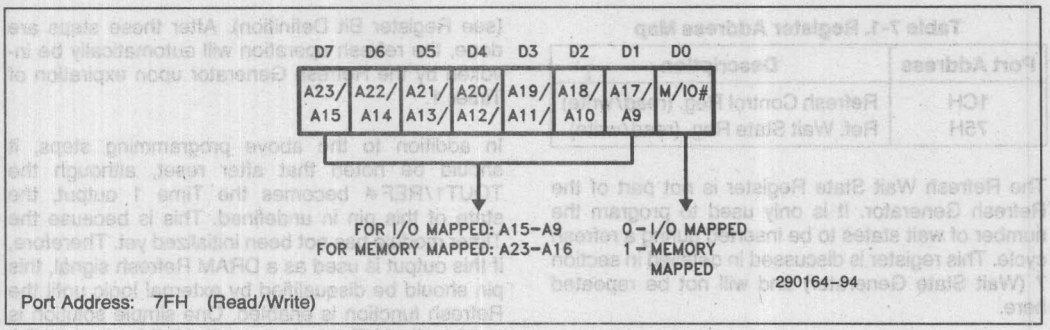


Figure 8-1. Relocation Register

Note that the Relocation Register is part of the internal register set of the 82370. It has a port address of 7FH. Therefore, any time the content of the Relocation Register is changed, the physical location of this register will also be moved. Upon reset of the 82370, the content of the Relocation Register will be cleared. This implies that the 82370 will respond to its I/O addresses in the range of 0000H to 00FFH.

8.1.1 I/O-MAPPED 82370

As shown in the figure, Bit 0 of the Relocation Register determines whether the 82370 registers are to be memory-mapped or I/O mapped. When Bit 0 is set to '0', the 82370 will respond to I/O Addresses. Address signals BHE#, BLE#, A1–A7 will be used to select one of the internal registers to be accessed. Bit 1 to Bit 7 of the Relocation Register will correspond to A9 to A15 of the Address bus, respectively. Together with A8 implied to be '0', A15 to A8 will be fully decoded by the 82370. The following shows how the 82370 is mapped into the I/O address space.

Example

Relocation Register = 11001110 (0CEH)

82370 will respond to I/O address range from 0CE00H to 0CEFFH.

Therefore, this I/O mapping mechanism allows the 82370 internal registers to be located on any even, contiguous, 256 byte boundary of the system I/O space.

8.1.2 MEMORY-MAPPED 82370

When Bit 0 of the Relocation Register is set to '1', the 82370 will respond to memory addresses. Again, Address signals BHE#, BLE#, A1–A7 will be used to select one of the internal registers to be accessed. Bit 1 to Bit 7 of the Relocation Register will correspond to A17–A23, respectively. A16 is assumed to be '0', and A8–A15 are ignored. Consider the following example.

Example

Relocation Register = 10100111 (0A7H)

The 82370 will respond to memory addresses in the range of A6XX00H to A60XXFFH (where 'X' is don't care).

This scheme implies that the internal registers can be located in any even, contiguous, 2**16 byte page of the memory space.

8.2 Address Decoding

As mentioned previously, the 82370 internal registers do not occupy the entire contiguous 256 address locations. Some of the locations are 'unoccupied'. The 82370 always decodes the lower 8 address signals (BHE#, BLE#, A1–A7) to determine if any one of its registers is being accessed. If the address does not correspond to any of its registers, the 82370 will not respond. This allows external devices to be located within the 'holes' in the 82370 address space. Note that there are several unused addresses reserved for future Intel peripheral devices.

8.3 Chip-Select (CHPSEL#)

The Chip-Select signal (CHPSEL#) will go active when the 82370 is addressed in a Slave bus

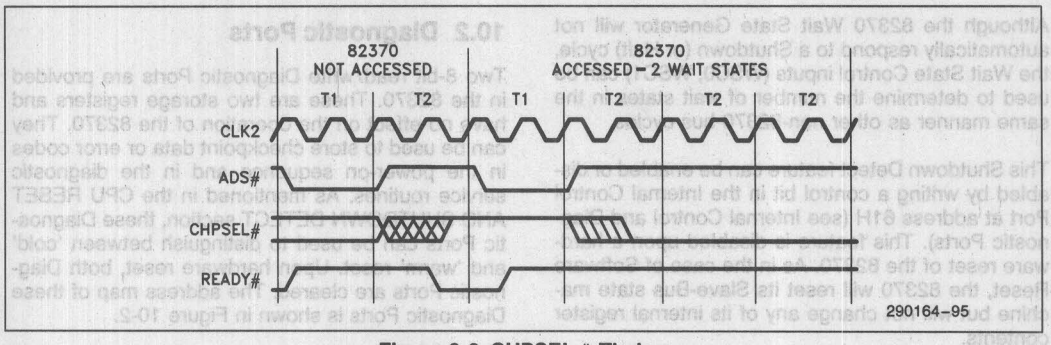


Figure 8-2. CHPSEL# Timing

cycle (either read or write), or in an interrupt acknowledge cycle in which the 82370 will drive the Data Bus. For a given bus cycle, CHPSEL# becomes active and valid in the first T2 (in a non-pipelined cycle) or in T1P (in a pipelined cycle). It will stay valid until the cycle is terminated by READY# driven active. As CHPSEL# becomes valid well before the 82370 drives the Data Bus, it can be used to control the transceivers that connect the local CPU bus to the system bus. The timing diagram of CHPSEL# is shown in Figure 8-2.

9.0 CPU RESET AND SHUTDOWN DETECT

The 82370 will activate the CPURST signal to reset the host processor when one of the following conditions occurs:

— 82370 RESET is active;

— 82370 detects a 80376 Shutdown cycle (this feature can be disabled);

— CPURST software command is issued to 80376.

Whenever the CPURST signal is activated, the 82370 will reset its own internal Slave-Bus state machine.

9.1 Hardware Reset

Following a hardware reset, the 82370 will assert its CPURST output to reset the host processor. This output will stay active for as long as the RESET input is active. During a hardware reset, the 82370 internal registers will be initialized as defined in the corresponding functional descriptions.

9.2 Software Reset

CPURST can be generated by writing the following bit pattern into 82370 register location 64H.

D7 . . . D0
1 1 1 1 X X X 0

The Write operation into this port is considered as an 82370 access and the internal Wait State Generator will automatically determine the required number of wait states. The CPURST will be active following the completion of the Write cycle to this port. This signal will last for 62 CLK2 periods. The 82370 should not be accessed until the CPURST is deactivated.

This internal port is Write-Only and the 82370 will not respond to a Read operation to this location. Also, during a software reset command, the 82370 will reset its Slave-Bus state machine. However, its internal registers remain unchanged. This allows the operating system to distinguish a 'warm' reset by reading any 82370 internal register previously programmed for a non-default value. The Diagnostic registers can be used for this purpose (see Internal Control and Diagnostic Ports).

9.3 Shutdown Detect

The 82370 is constantly monitoring the Bus Cycle Definition signals (M/IO#, D/C#, W/R#) and is able to detect when the 80376 is in a Shutdown bus cycle. Upon detection of a processor shutdown, the 82370 will activate the CPURST output for 62 CLK2 periods to reset the host processor. This signal is generated after the Shutdown cycle is terminated by the READY# signal.

Although the 82370 Wait State Generator will not automatically respond to a Shutdown (or Halt) cycle, the Wait State Control inputs (WSC0, WSC1) can be used to determine the number of wait states in the same manner as other non-82370 bus cycles.

This Shutdown Detect feature can be enabled or disabled by writing a control bit in the Internal Control Port at address 61H (see Internal Control and Diagnostic Ports). This feature is disabled upon a hardware reset of the 82370. As in the case of Software Reset, the 82370 will reset its Slave-Bus state machine but will not change any of its internal register contents.

10.0 INTERNAL CONTROL AND DIAGNOSTIC PORTS

10.1 Internal Control Port

The format of the Internal Control Port of the 82370 is shown in Figure 10-1. This Control Port is used to enable/disable the Processor Shutdown Detect mechanism as well as controlling the Gate inputs of the Timer 2 and 3. Note that this is a Write-Only port. Therefore, the 82370 will not respond to a read operation to this port. Upon hardware reset, this port will be cleared; i.e., the Shutdown Detect feature and the Gate inputs of Timer 2 and 3 are disabled.

Port Address: 61H (Write only)

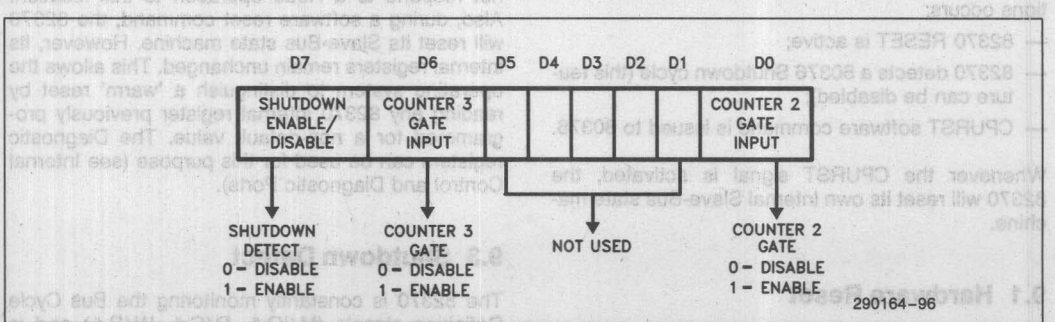


Figure 10-1. Internal Control Port

10.2 Diagnostic Ports

Two 8-bit read/write Diagnostic Ports are provided in the 82370. These are two storage registers and have no effect on the operation of the 82370. They can be used to store checkpoint data or error codes in the power-on sequence and in the diagnostic service routines. As mentioned in the CPU RESET AND SHUTDOWN DETECT section, these Diagnostic Ports can be used to distinguish between 'cold' and 'warm' reset. Upon hardware reset, both Diagnostic Ports are cleared. The address map of these Diagnostic Ports is shown in Figure 10-2.

Port		Address
Diagnostic Port 1	(Read/Write)	80H
Diagnostic Port 2	(Read/Write)	88H

Figure 10-2. Address Map of Diagnostic Ports

11.0 INTEL RESERVED I/O PORTS

There are nineteen I/O ports in the 82370 address space which are reserved for Intel future peripheral device use only. Their address locations are: 10H, 12H, 14H, 16H, 2AH, 3DH, 3EH, 45H, 46H, 76H, 77H, 7DH, 7EH, CCH, CDH, D0H, D2H, D4H, and D6H. These addresses should not be used in the system since the 82370 will respond to read/write operations to these locations and bus contention may occur if any peripheral is assigned to the same address location.

12.0 PACKAGE THERMAL SPECIFICATIONS

The intel 82370 Integrated System Peripheral is specified for operation when case temperature is within the range of 0°C to 78°C for the ceramic 132-pin PGA package, and 68°C for the 100-pin plastic package. The case temperature may be measured in any environment, to determine whether the 82370 is within specified operating range. The case temperature should be measured at the center of the top surface opposite the pins.

The ambient temperature is guaranteed as long as T_C is not violated. The ambient temperature can be calculated from the θ_{jc} and θ_{ja} from the following equations:

$$T_J = T_c + P^*\theta_{jc}$$
$$T_A = T_j - P^*\theta_{ja}$$
$$T_C = T_a + P^*[\theta_{ja} - \theta_{jc}]$$

Values for θ_{ja} and θ_{jc} are given in Table 12.1 for the 100-lead fine pitch. θ_{ja} is given at various airflows. Table 12.2 shows the maximum T_a allowable (without exceeding T_C) at various airflows. Note that T_a can be improved further by attaching "fins" or a "heat sink" to the package. P is calculated using the maximum ***hot*** I_{CC}.

Table 12.1 82370 Package Thermal Characteristics
Thermal Resistances (°C/Watt) θ_{jc} and θ_{ja}

Package	θ_{jc}	θ_{ja} Versus Airflow-ft³/min (m³/sec)					
		0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
100L Fine Pitch	7	33	27	24	21	18	17
132L PGA	2	21	17	14	12	11	10

Table 12.2 82370 Maximum Allowable Ambient Temperature at Various Airflows

Package	θ_{jc}	T_a(c) Versus Airflow-ft³/min (m³/sec)					
		0 (0)	200 (1.01)	400 (2.03)	600 (3.04)	800 (4.06)	1000 (5.07)
100L Fine Pitch	7	63	74	79	85	91	92
132L PGA	2	74	83	88	93	97	99

100L PQFP Pkg:
$T_c = T_a + P^*(\theta_{ja} - \theta_{jc})$
$T_c = 63 + 1.21(33 - 7)$
$T_c = 63 + 1.21(26)$
$T_c = 63 + 31.46$
$T_c = 94\,°C$

132L PGA Pkg:
$T_c = T_a + P^*(\theta_{ja} - \theta_{jc})$
$T_c = 74 + 1.21(21 - 2)$
$T_c = 74 + 1.21(19)$
$T_c = 74 + 22.99$
$T_c = 96\,°C$

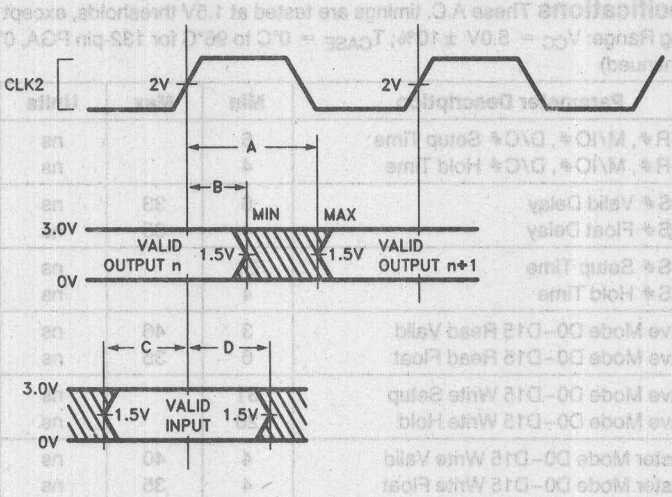
9

13.0 ELECTRICAL SPECIFICATIONS

82370 D.C. Specifications Functional Operating Range:
V_{CC} = 5.0V ±10%; T_{CASE} = 0°C to 96°C for 132-pin PGA, 0°C to 94°C for 100-pin plastic

Symbol	Parameter Description	Min	Max	Units	Notes
V_{IL}	Input Low Voltage	−0.3	0.8	V	(Note 1)
V_{IH}	Input High Voltage	2.0	V_{CC} + 0.3	V	
V_{ILC}	CLK2 Input Low Voltage	−0.3	0.8	V	(Note 1)
V_{IHC}	CLK2 Input High Voltage	V_{CC} − 0.8	V_{CC} + 0.3	V	
V_{OL}	Output Low Voltage I_{OL} = 4 mA: A_{1-23}, D_{0-15}, BHE#, BLE# I_{OL} = 5 mA: All Others		0.45 0.45	V V	
V_{OH}	Output High Voltage				
I_{OH} = −1 mA	A_{23}–A_1, D_{15}–D_0, BHE#, BLE#	2.4		V	(Note 5)
I_{OH} = −0.2 mA	A_{23}–A_1, D_{15}–D_0, BHE#, BLE#	V_{CC} − 0.5		V	(Note 5)
I_{OH} = −0.9 mA	All Others	2.4		V	(Note 5)
I_{OH} = −0.18 mA	All Others	V_{CC} − 0.5		V	(Note 5)
I_{LI}	Input Leakage Current All Inputs Except: IRQ11#–IRQ23# EOP#, TOUT2/IRQ3# DREQ4/IRQ9#		±15	µA	
I_{LI1}	Input Leakage Current Inputs: IRQ11#–IRQ23# EOP#, TOUT2/IRQ3 DREQ4/IRQ9	10	−300	µA	0 < V_{IN} < V_{CC} (Note 3)
I_{LO}	Output Leakage Current		±15	µA	0 < V_{IN} < V_{CC}
I_{CC}	Supply Current (CLK2 = 32 MHz)		220	mA	(Note 4)
C_I	Input Capacitance		12	pF	(Note 2)
C_{CLK}	CLK2 Input Capacitance		20	pF	(Note 2)

NOTES:
1. Minimum value is not 100% tested.
2. f_C = 1 MHz; sampled only.
3. These pins have weak internal pullups. They sould not be left floating.
4. I_{CC} is specified with inputs driven to CMOS levels, and outputs driving CMOS loads. I_{CC} may be higher if inputs are driven to TTL levels, or if outputs are driving TTL loads.
5. Tested at the minimum operating frequency of the part.



LEGEND:
A—Maximum output delay specification
B—Minimum output delay specification
C—Minimum input setup specification
D—Minimum input hold specification

Figure 13-1. Drive Levels and Measurement Points for A.C. Specification

82370 A.C. Specifications These A.C. timings are tested at 1.5V thresholds, except as noted. Functional Operating Range: $V_{CC} = 5.0V \pm 10\%$; $T_{CASE} = 0°C$ to 96°C for 132-pin PGA, 0°C to 94°C for 100-pin plastic

Symbol	Parameter Description	Min	Max	Units	Notes
	Operating Frequency 1/(t1a × 2)	4	16	MHz	
t1	CLK2 Period	31	125	ns	
t2a	CLK2 High Time	9		ns	At 2.0V
t2b	CLK2 High Time	5		ns	At $V_{CC} - 0.8V$
t3a	CLK2 Low Time	9		ns	At 2.0V
t3b	CLK2 Low Time	7		ns	At 0.8V
t4	CLK2 Fall Time		7	ns	$V_{CC} - 0.8V$ to 0.8V
t5	CLK2 Rise Time		7	ns	0.8V to $V_{CC} - 0.8V$
t6	A1–A23, BHE#, BLE#	4	36	ns	$C_L = 120$ pF
t7	EDACK0–EDACK2 Valid Delay A1–A23, BHE#, BLE# EDACK0–EDACK3 Float Delay	4	40	ns	(Note 1)
t8	A1–A23, BHE#, BLE# Setup Time	6		ns	
t9	A1–A23, BHE#, BLE# Hold Time	4		ns	
t10	W/R#, M/IO#, D/C# Valid Delay	4	33	ns	$C_L = 75$ pF
t11	W/R#, M/IO#, D/C# Float Delay	4	35	ns	(Note 1)

9

82370 A.C. Specifications These A.C. timings are tested at 1.5V thresholds, except as noted. Functional Operating Range: V_{CC} = 5.0V ±10%; T_{CASE} = 0°C to 96°C for 132-pin PGA, 0°C to 94°C for 100-pin plastic (Continued)

Symbol	Parameter Description	Min	Max	Units	Notes
t12	W/R#, M/IO#, D/C# Setup Time	6		ns	
t13	W/R#, M/IO#, D/C# Hold Time	4		ns	
t14	ADS# Valid Delay	6	33	ns	CL = 50 pF
t15	ADS# Float Delay	4	35	ns	(Note 1)
t16	ADS# Setup Time	21		ns	
t17	ADS# Hold Time	4		ns	
t18	Slave Mode D0–D15 Read Valid	3	46	ns	C_L = 120 pF
t19	Slave Mode D0–D15 Read Float	6	35	ns	(Note 1)
t20	Slave Mode D0–D15 Write Setup	31		ns	
t21	Slave Mode D0–D15 Write Hold	26		ns	
t22	Master Mode D0–D15 Write Valid	4	40	ns	C_L = 120 pF
t23	Master Mode D0–D15 Write Float	4	35	ns	(Note 1)
t24	Master Mode D0–D15 Read Setup	8		ns	
t25	Master Mode D0–D15 Read Hold	6		ns	
t26	READY# Setup Time	19		ns	
t27	READY# Hold Time	4		ns	
t28	WSC0–WSC1 Setup Time	6		ns	
t29	WSC0–WSC1 Hold Time	21		ns	
t30	RESET Setup Time	13		ns	
t31	RESET Hold Time	4		ns	
t32	READYO# Valid Delay	4	31	ns	C_L = 25 pF
t33	CPURST Valid Delay (Falling Edge Only)	2	18	ns	C_L = 50 pF
t34	HOLD Valid Delay	5	33	ns	C_L = 100 pF
t35	HLDA Setup Time	21		ns	
t36	HLDA Hold Time	6		ns	
t37a	EOP# Setup (Synchronous)	21		ns	
t38a	EOP# Hold (Synchronous)	6		ns	
t37b	EOP# Setup (Asynchronous)	11		ns	
t38b	EOP# Hold (Asynchronous)	11		ns	
t39	EOP# Valid Delay (Falling Edge Only)	5	38	ns	C_L = 100 pF
t40	EOP# Float Delay	5	40	ns	(Note 1)
t41a	DREQ Setup (Synchronous)	21		ns	
t42a	DREQ Hold (Synchronous)	4		ns	
t41b	DREQ Setup (Asynchronous)	11		ns	
t42b	DREQ Hold (Asynchronous)	11		ns	
t43	INT Valid Delay from IRQn		500	ns	
t44	NA# Setup Time	5		ns	
t45	NA# Hold Time	15		ns	

82370 A.C. Specifications These A.C. timings are tested at 1.5V thresholds, except as noted. Functional Operating Range: V_{CC} = 5.0V ±10%; T_{CASE} = 0°C to 96°C for 132-pin PGA, 0°C to 94°C for 100-pin plastic (Continued)

Symbol	Parameter Description	Min	Max	Units	Notes
t46	CLKIN Frequency	DC	10	MHz	
t47	CLKIN High Time	30		ns	2.0V
t48	CLKIN Low Time	50		ns	0.8V
t49	CLKIN Rise Time		10	ns	0.8V to 3.7V
t50	CLKIN Fall Time		10	ns	3.7V to 0.8V
	TOUT1#/REF# Valid Delay				
t51	from CLK2 (Refresh)	4	36	ns	C_L = 120 pF
t52	from CLKIN (Timer)	3	93	ns	C_L = 120 pF
t53	TOUT2# Valid Delay (from CLKIN, Falling Edge Only)	3	93	ns	C_L = 120 pf
t54	TOUT2# Float Delay	3	36	ns	(Note 1)
t55	TOUT3# Valid Delay (from CLKIN)	3	93	ns	C_L = 120 pF
t56	CHPSEL# Valid Delay	1	35	ns	C_L = 25 pF

NOTE:
1. Float condition occurs when the maximum output current becomes less than I_{LO} in magnitude. Float delay is not tested. For testing purposes, the float condition occurs when the dynamic output driven voltage changes with current loads.

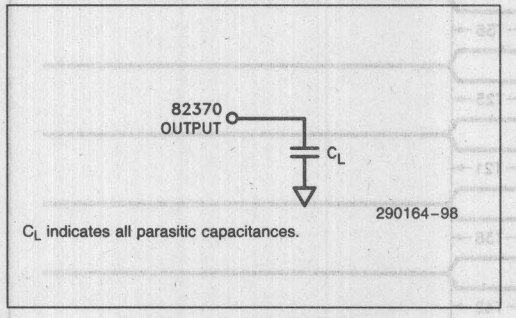


Figure 13-2. A.C. Test Load

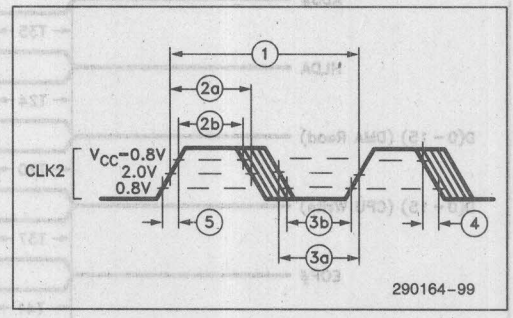


Figure 13-3

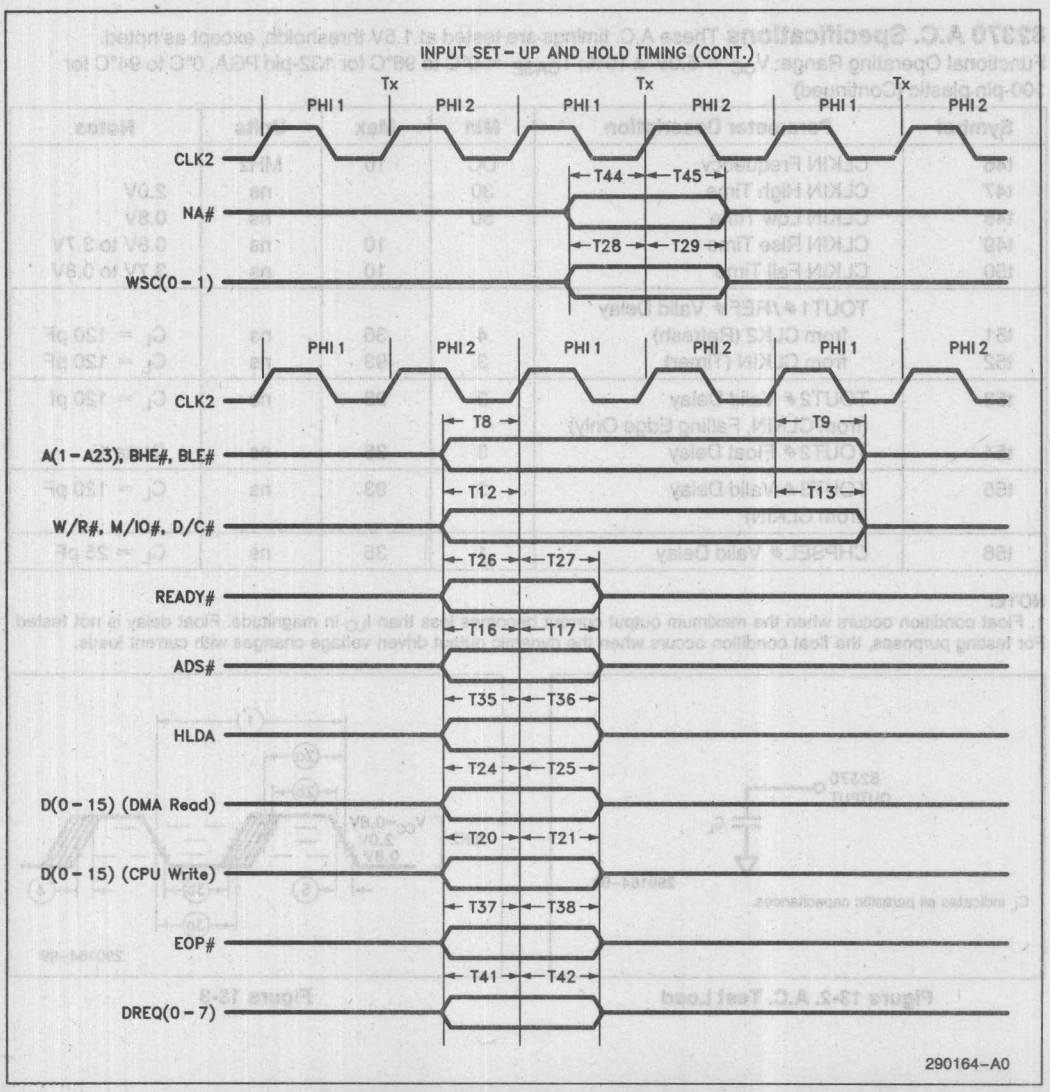


Figure 13-4. Input Setup and Hold Timing

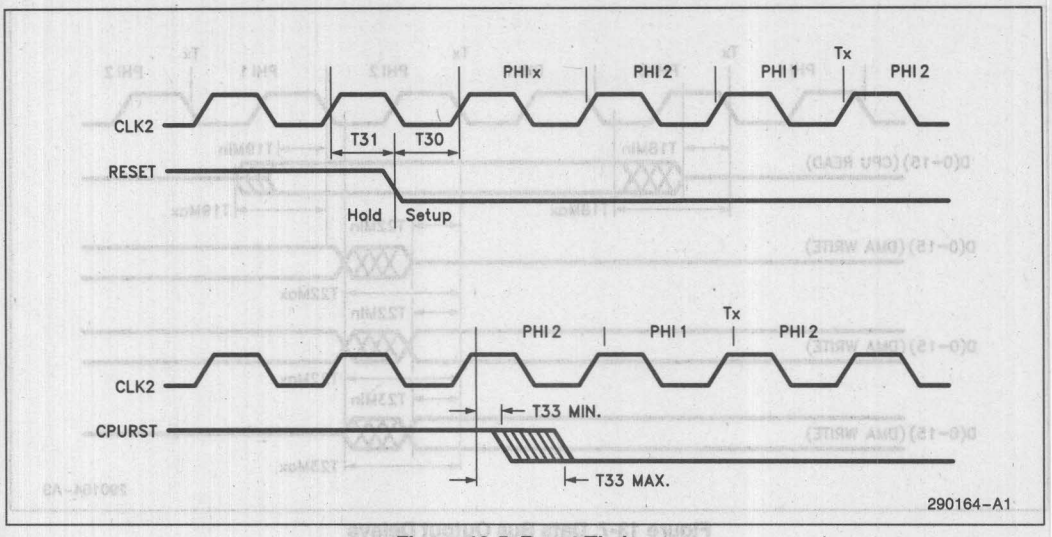


Figure 13-5. Reset Timing

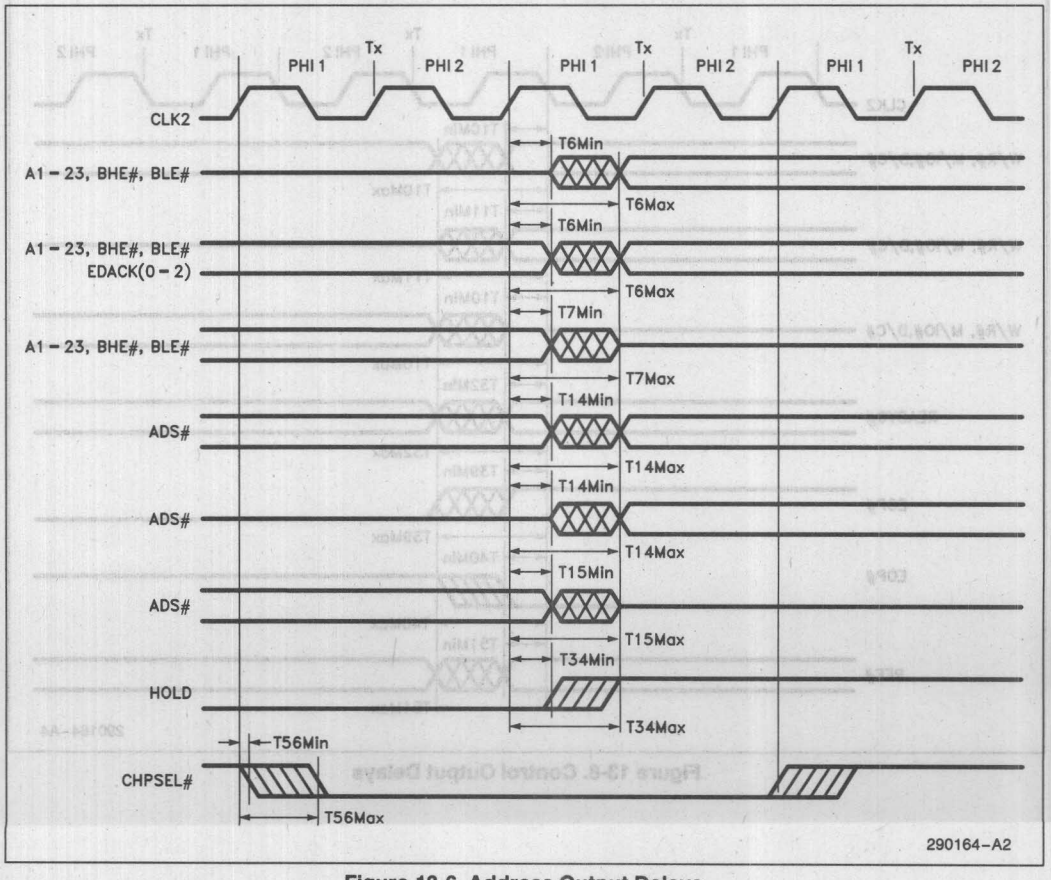


Figure 13-6. Address Output Delays

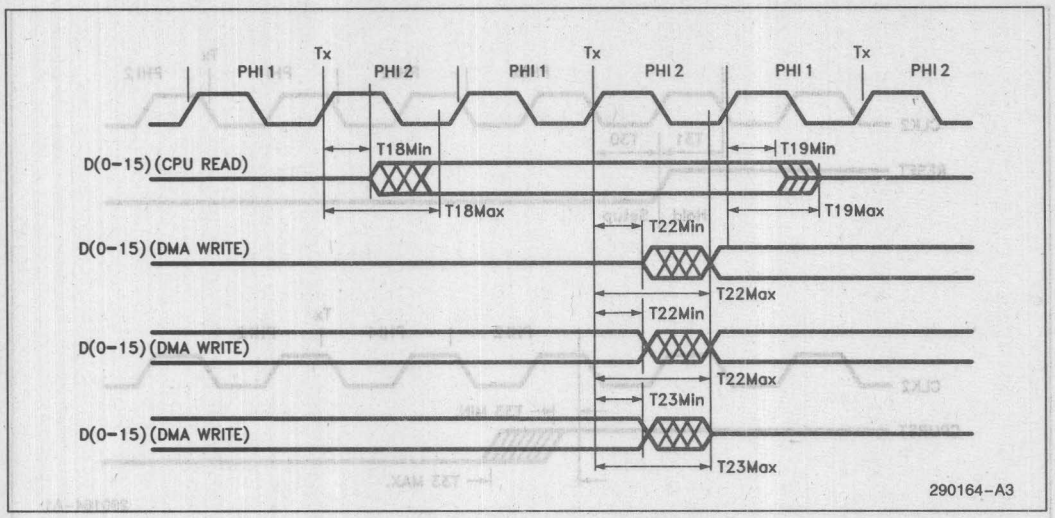


Figure 13-7. Data Bus Output Delays

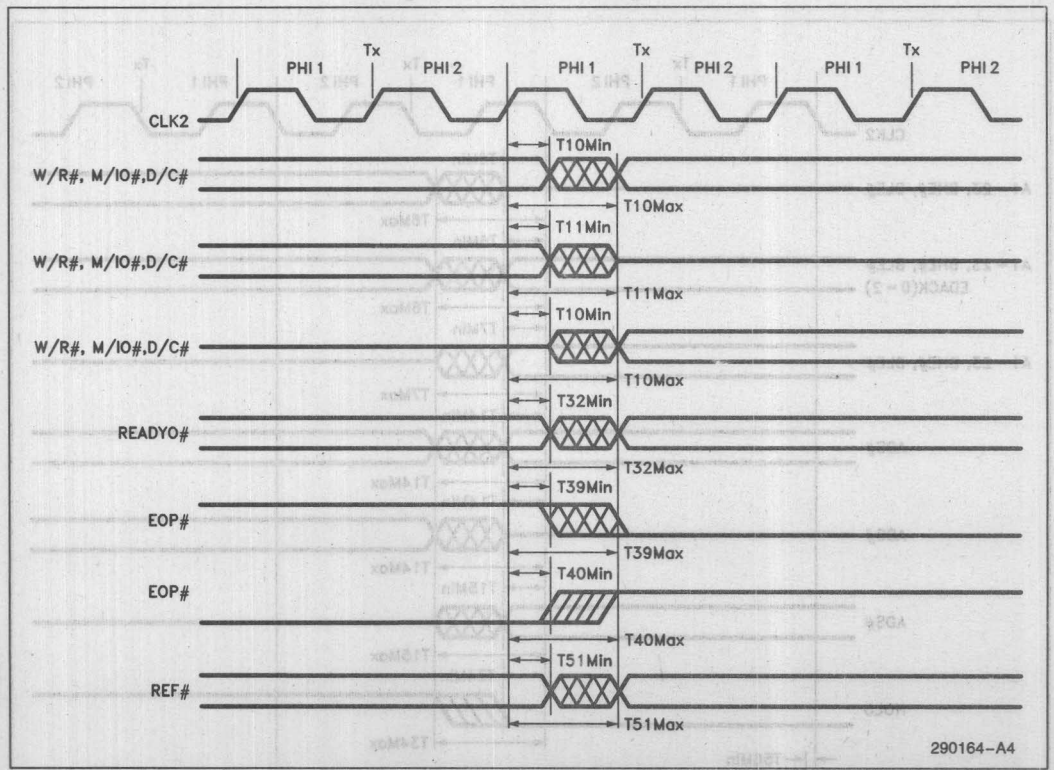


Figure 13-8. Control Output Delays

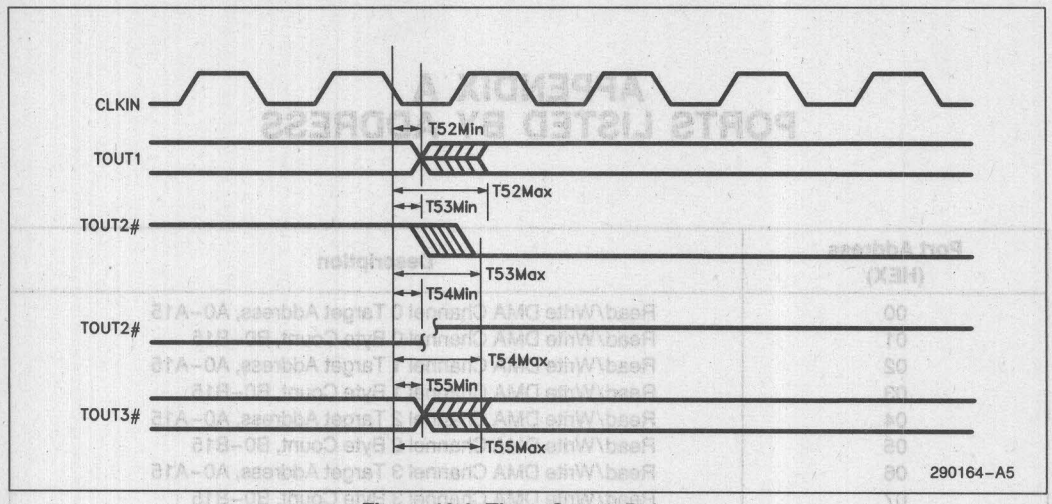


Figure 13-9. Timer Output Delays

APPENDIX A
PORTS LISTED BY ADDRESS

Port Address (HEX)	Description
00	Read/Write DMA Channel 0 Target Address, A0–A15
01	Read/Write DMA Channel 0 Byte Count, B0–B15
02	Read/Write DMA Channel 1 Target Address, A0–A15
03	Read/Write DMA Channel 1 Byte Count, B0–B15
04	Read/Write DMA Channel 2 Target Address, A0–A15
05	Read/Write DMA Channel 2 Byte Count, B0–B15
06	Read/Write DMA Channel 3 Target Address, A0–A15
07	Read/Write DMA Channel 3 Byte Count, B0–B15
08	Read/Write DMA Channel 0–3 Status/Command I Register
09	Read/Write DMA Channel 0–3 Software Request Register
0A	Write DMA Channel 0–3 Set-Reset Mask Register
0B	Write DMA Channel 0–3 Mode Register I
0C	Write Clear Byte-Pointer FF
0D	Write DMA Master-Clear
0E	Write DMA Channel 0–3 Clear Mask Register
0F	Read/Write DMA Channel 0–3 Mask Register
10	Intel Reserved
11	Read/Write DMA Channel 0 Byte Count, B16–B23
12	Intel Reserved
13	Read/Write DMA Channel 1 Byte Count, B16–B23
14	Intel Reserved
15	Read/Write DMA Channel 2 Byte Count, B16–B23
16	Intel Reserved
17	Read/Write DMA Channel 3 Byte Count, B16–B23
18	Write DMA Channel 0–3 Bus Size Register
19	Read/Write DMA Channel 0–3 Chaining Register
1A	Write DMA Channel 0–3 Command Register II
1B	Write DMA Channel 0–3 Mode Register II
1C	Read/Write Refresh Control Register
1E	Reset Software Request Interrupt
20	Write Bank B ICW1, OCW2 or OCW3 Read Bank B Poll, Interrupt Request or In-Service Status Register
21	Write Bank B ICW2, ICW3, ICW4 or OCW1 Read Bank B Interrupt Mask Register
22	Read Bank B ICW2
28	Read/Write IRQ8 Vector Register
29	Read/Write IRQ9 Vector Register
2A	Reserved

Port Address (HEX)	Description
2B	Read/Write IRQ11 Vector Register
2C	Read/Write IRQ12 Vector Register
2D	Read/Write IRQ13 Vector Register
2E	Read/Write IRQ14 Vector Register
2F	Read/Write IRQ15 Vector Register
30	Write Bank A ICW1, OCW2 or OCW3
	Read Bank A Poll, Interrupt Request or In-Service Status Register
31	Write Bank A ICW2, ICW3, ICW4 or OCW1
	Read Bank A Interrupt Mask Register
32	Read Bank A ICW2
38	Read/Write IRQ0 Vector Register
39	Read/Write IRQ1 Vector Register
3A	Read/Write IRQ1.5 Vector Register
3B	Read/Write IRQ3 Vector Register
3C	Read/Write IRQ4 Vector Register
3D	Reserved
3E	Reserved
3F	Read/Write IRQ7 Vector Register
40	Read/Write Counter 0 Register
41	Read/Write Counter 1 Register
42	Read/Write Counter 2 Register
43	Write Control Word Register I—Counter 0, 1, 2
44	Read/Write Counter 3 Register
45	Reserved
46	Reserved
47	Write Word Register II—Counter 3
61	Write Internal Control Port
64	Write CPU Reset Register (Data—1111XXX0H)
72	Read/Write Wait State Register 0
73	Read/Write Wait State Register 1
74	Read/Write Wait State Register 2
75	Read/Write Refresh Wait State Register
76	Reserved
77	Reserved
7D	Reserved
7E	Reserved
7F	Read/Write Relocation Register
80	Read/Write Internal Diagnostic Port 0
81	Read/Write DMA Channel 2 Target Address, A16–A23
82	Read/Write DMA Channel 3 Target Address, A16–A23
83	Read/Write DMA Channel 1 Target Address, A16–A23
87	Read/Write DMA Channel 0 Target Address, A16–A23
88	Read/Write Internal Diagnostic Port 1
89	Read/Write DMA Channel 6 Target Address, A16–A23
8A	Read/Write DMA Channel 7 Target Address, A16–A23
8B	Read/Write DMA Channel 5 Target Address, A16–A23
8F	Read/Write DMA Channel 4 Target Address, A16–A23

Port Address (HEX)	Description
90	Read/Write DMA Channel 0 Requester Address, A0–A15
91	Read/Write DMA Channel 0 Requester Address, A16–A23
92	Read/Write DMA Channel 1 Requester Address, A0–A15
93	Read/Write DMA Channel 1 Requester Address, A16–A23
94	Read/Write DMA Channel 2 Requester Address, A0–A15
95	Read/Write DMA Channel 2 Requester Address, A16–A23
96	Read/Write DMA Channel 3 Requester Address, A0–A15
97	Read/Write DMA Channel 3 Requester Address, A16–A23
98	Read/Write DMA Channel 4 Requester Address, A0–A15
99	Read/Write DMA Channel 4 Requester Address, A16–A23
9A	Read/Write DMA Channel 5 Requester Address, A0–A15
9B	Read/Write DMA Channel 5 Requester Address, A16–A23
9C	Read/Write DMA Channel 6 Requester Address, A0–A15
9D	Read/Write DMA Channel 6 Requester Address, A16–A23
9E	Read/Write DMA Channel 7 Requester Address, A0–A15
9F	Read/Write DMA Channel 7 Requester Address, A16–A23
A0	Write Bank C ICW1, OCW2 or OCW3
	Read Bank C Poll, Interrupt Request or In-Service Status Register
A1	Write Bank C ICW2, ICW3, ICW4 or OCW1
	Read Bank C Interrupt Mask Register
A2	Read Bank C ICW2
A8	Read/Write IRQ16 Vector Register
A9	Read/Write IRQ17 Vector Register
AA	Read/Write IRQ18 Vector Register
AB	Read/Write IRQ19 Vector Register
AC	Read/Write IRQ20 Vector Register
AD	Read/Write IRQ21 Vector Register
AE	Read/Write IRQ22 Vector Register
AF	Read/Write IRQ23 Vector Register
C0	Read/Write DMA Channel 4 Target Address, A0–A15
C1	Read/Write DMA Channel 4 Byte Count, B0–B15
C2	Read/Write DMA Channel 5 Target Address, A0–A15
C3	Read/Write DMA Channel 5 Byte Count, B0–B15
C4	Read/Write DMA Channel 6 Target Address, A0–A15
C5	Read/Write DMA Channel 6 Byte Count, B0–B15
C6	Read/Write DMA Channel 7 Target Address, A0–A15
C7	Read/Write DMA Channel 7 Byte Count, B0–B15
C8	Read DMA Channel 4–7 Status/Command I Register
C9	Read/Write DMA Channel 4–7 Software Request Register
CA	Write DMA Channel 4–7 Set-Reset Mask Register
CB	Write DMA Channel 4–7 Mode Register I
CC	Reserved
CD	Reserved
CE	Write DMA Channel 4–7 Clear Mask Register
CF	Read/Write DMA Channel 4–7 Mask Register
D0	Intel Reserved
D1	Read/Write DMA Channel 4 Byte Count, B16–B23
D2	Intel Reserved
D3	Read/Write DMA Channel 5 Byte Count, B16–B23

Port Address (HEX)	Description
D4	Intel Reserved
D5	Read/Write DMA Channel 6 Byte Count, B16–B23
D6	Intel Reserved
D7	Read/Write DMA Channel 7 Byte Count, B16–B23
D8	Write DMA Channel 4–7 Bus Size Register
D9	Read/Write DMA Channel 4–7 Chaining Register
DA	Write DMA Channel 4–7 Command Register II
DB	Write DMA Channel 4–7 Mode Register II

APPENDIX B
PORTS LISTED BY FUNCTION

Port Address (HEX)	Description
DMA CONTROLLER	
0D	Write DMA Master-Clear
0C	Write DMA Clear Byte-Pointer FF
08	Read/Write DMA Channel 0–3 Status/Command I Register
C8	Read/Write DMA Channel 4–7 Status/Command I Register
1A	Write DMA Channel 0–3 Command Register II
DA	Write DMA Channel 4–7 Command Register II
0B	Write DMA Channel 0–3 Mode Register I
CB	Write DMA Channel 4–7 Mode Register I
1B	Write DMA Channel 0–3 Mode Register II
DB	Write DMA Channel 4–7 Mode Register II
09	Read/Write DMA Channel 0–3 Software Request Register
C9	Read/Write DMA Channel 4–7 Software Request Register
1E	Reset Software Request Interrupt
0E	Write DMA Channel 0–3 Clear Mask Register
CE	Write DMA Channel 4–7 Clear Mask Register
0F	Read/Write DMA Channel 0–3 Mask Register
CF	Read/Write DMA Channel 4–7 Mask Register
0A	Write DMA Channel 0–3 Set-Reset Mask Register
CA	Write DMA Channel 4–7 Set-Reset Mask Register
18	Write DMA Channel 0–3 Bus Size Register
D8	Write DMA Channel 4–7 Bus Size Register
19	Read/Write DMA Channel 0–3 Chaining Register
D9	Read/Write DMA Channel 4–7 Chaining Register
00	Read/Write DMA Channel 0 Target Address, A0–A15
87	Read/Write DMA Channel 0 Target Address, A16–A23
01	Read/Write DMA Channel 0 Byte Count, B0–B15
11	Read/Write DMA Channel 0 Byte Count, B16–B23
90	Read/Write DMA Channel 0 Requester Address, A0–A15
91	Read/Write DMA Channel 0 Requester Address, A16–A23

Port Address (HEX)	Description
DMA CONTROLLER (Continued)	
02	Read/Write DMA Channel 1 Target Address, A0–A15
83	Read/Write DMA Channel 1 Target Address, A16–A23
03	Read/Write DMA Channel 1 Byte Count, B0–B15
13	Read/Write DMA Channel 1 Byte Count, B16–B23
92	Read/Write DMA Channel 1 Requester Address, A0–A15
93	Read/Write DMA Channel 1 Requester Address, A16–A23
04	Read/Write DMA Channel 2 Target Address, A0–A15
81	Read/Write DMA Channel 2 Target Address, A16–A23
05	Read/Write DMA Channel 2 Byte Count, B0–B15
15	Read/Write DMA Channel 2 Byte Count, B16–B23
94	Read/Write DMA Channel 2 Requester Address, A0–A15
95	Read/Write DMA Channel 2 Requester Address, A16–A23
06	Read/Write DMA Channel 3 Target Address, A0–A15
82	Read/Write DMA Channel 3 Target Address, A16–A23
07	Read/Write DMA Channel 3 Byte Count, B0–B15
17	Read/Write DMA Channel 3 Byte Count, B16–B23
96	Read/Write DMA Channel 3 Requester Address, A0–A15
97	Read/Write DMA Channel 3 Requester Address, A16–A23
C0	Read/Write DMA Channel 4 Target Address, A0–A15
8F	Read/Write DMA Channel 4 Target Address, A16–A23
C1	Read/Write DMA Channel 4 Byte Count, B0–B15
D1	Read/Write DMA Channel 4 Byte Count, B16–B23
98	Read/Write DMA Channel 4 Requester Address, A0–A15
99	Read/Write DMA Channel 4 Requester Address, A16–A23
C2	Read/Write DMA Channel 5 Target Address, A0–A15
8B	Read/Write DMA Channel 5 Target Address, A16–A23
C3	Read/Write DMA Channel 5 Byte Count, B0–B15
D3	Read/Write DMA Channel 5 Byte Count, B16–B23
9A	Read/Write DMA Channel 5 Requester Address, A0–A15
9B	Read/Write DMA Channel 5 Requester Address, A16–A23
C4	Read/Write DMA Channel 6 Target Address, A0–A15
89	Read/Write DMA Channel 6 Target Address, A16–A23
C5	Read/Write DMA Channel 6 Byte Count, B0–B15
D5	Read/Write DMA Channel 6 Byte Count, B16–B23
9C	Read/Write DMA Channel 6 Requester Address, A0–A15
9D	Read/Write DMA Channel 6 Requester Address, A16–A23
C6	Read/Write DMA Channel 7 Target Address, A0–A15
8A	Read/Write DMA Channel 7 Target Address, A16–A23
C7	Read/Write DMA Channel 7 Byte Count, B0–B15
D7	Read/Write DMA Channel 7 Byte Count, B16–B23
9E	Read/Write DMA Channel 7 Requester Address, A0–A15
9F	Read/Write DMA Channel 7 Requester Address, A16–A23

Port Address (HEX)	Description
INTERRUPT CONTROLLER	
20	Write Bank B ICW1, OCW2 or OCW3
	Read Bank B Poll, Interrupt Request or In-Service Status Register
21	Write Bank B ICW2, ICW3, ICW4 or OCW1
	Read Bank B Interrupt Mask Register
22	Read Bank B ICW2
28	Read/Write IRQ8 Vector Register
29	Read/Write IRQ9 Vector Register
2A	Reserved
2B	Read/Write IRQ11 Vector Register
2C	Read/Write IRQ12 Vector Register
2D	Read/Write IRQ13 Vector Register
2E	Read/Write IRQ14 Vector Register
2F	Read/Write IRQ15 Vector Register
A0	Write Bank C ICW1, OCW2 or OCW3
	Read Bank C Poll, Interrupt Request or In-Service Status Register
A1	Write Bank C ICW2, ICW3, ICW4 or OCW1
	Read Bank C Interrupt Mask Register
A2	Read Bank C ICW2
A8	Read/Write IRQ16 Vector Register
A9	Read/Write IRQ17 Vector Register
AA	Read/Write IRQ18 Vector Register
AB	Read/Write IRQ19 Vector Register
AC	Read/Write IRQ20 Vector Register
AD	Read/Write IRQ21 Vector Register
AE	Read/Write IRQ22 Vector Register
AF	Read/Write IRQ23 Vector Register
30	Write Bank A ICW1, OCW2 or OCW3
	Read Bank A Poll, Interrupt Request or In-Service Status Register
31	Write Bank A ICW2, ICW3, ICW4 or OCW1
	Read Bank A Interrupt Mask Register
32	Read Bank A ICW2
38	Read/Write IRQ0 Vector Register
39	Read/Write IRQ1 Vector Register
3A	Read/Write IRQ1.5 Vector Register
3B	Read/Write IRQ3 Vector Register
3C	Read/Write IRQ4 Vector Register
3D	Reserved
3E	Reserved
3F	Read/Write IRQ7 Vector Register

Port Address (HEX)	Description
PROGRAMMABLE INTERVAL TIMER	
40	Read/Write Counter 0 Register
41	Read/Write Counter 1 Register
42	Read/Write Counter 2 Register
43	Write Control Word Register I—Counter 0, 1, 2
44	Read/Write Counter 3 Register
47	Write Word Register II—Counter 3
CPU RESET	
64	Write CPU Reset Register (Data—1111XXX0H)
WAIT STATE GENERATOR	
72	Read/Write Wait State Register 0
73	Read/Write Wait State Register 1
74	Read/Write Wait State Register 2
75	Read/Write Refresh Wait State Register
DRAM REFRESH CONTROLLER	
1C	Read/Write Refresh Control Register
INTERNAL CONTROL AND DIAGNOSTIC PORTS	
61	Write Internal Control Port
80	Read/Write Internal Diagnostic Port 0
88	Read/Write Internal Diagnostic Port 1
RELOCATION REGISTER	
7F	Read/Write Relocation Register
INTEL RESERVED PORTS	
10	Reserved
12	Reserved
14	Reserved
16	Reserved
2A	Reserved
3D	Reserved
3E	Reserved
45	Reserved
46	Reserved
76	Reserved
77	Reserved
7D	Reserved
7E	Reserved
CC	Reserved
CD	Reserved
D0	Reserved
D2	Reserved
D4	Reserved
D6	Reserved

APPENDIX C
SYSTEM NOTES

1. BHE# IN MASTER MODE.

In Master Mode, BHE# will be activated during DMA to/from 8-bit devices residing at even locations when the remaining byte count is greater than 1.

For example, if an 8-bit device is located at 00000000 Hex and the number of bytes to be transferred is > 1, the first address/BHE# combination will be 00000000/0. In some systems this will cause the bus controller to perform two 8-bit accesses, the first to 0000000 Hex and the second to 00000001 Hex. However, the 82370's DMA will only read/write one byte. This may or may not cause a problem in the system depending on what is located at 00000001 Hex.

Solution:

There are two solutions if BH# active is unacceptable. Of the two, number 2 is the cleanest and most recommended.

1. If there is an 8-bit device that uses DMA located at an even address, do not use that address + 1. The limitation of this solution is that the user must have complete control over what addresses will be used in the end system.

2. Do not allow the Bus Controller to split cycles for the DMA.

82370 TIMER UNIT NOTES

The 82370 DMA Controller with Integrated System Peripherals is functionally inconsistent with the data sheet. This document explains the behavior of the 82370 Timer Unit and outlines subsequent limitations of the timer unit. This document also provides recommended workarounds.

1.0 WRITE CYCLES TO THE 82370 TIMER UNIT:

This errata applies only to SLAVE WRITE cycles to the 82370 timer unit. During these cycles, the data being written into the 82370 timer unit may be corrupted if asynchronous CLKIN is not inhibited during a certain "window" of the write cycle.

1.1 Description

Please refer to Figure C-2.

During write cycles to the 82370 timer unit, the 82370 translates the 80376 interface signals such as #ADS, #W/R, #M/IO, and #D/C into several internal signals that control the operation of the internal sub-blocks (e.g. Timer Unit).

The 82370 timer uint is controlled by such internal signals. These internal signals are generated and sampled with respect to two separate clock signals: CLK2 (the system clock) and CLKIN (the 82370 timer unit clock).

Since the CLKIN and CLK2 clock signals are used internally to generate control signals for the interface to the timer unit, some timing parameters must be met in order for the interface logic to function properly.

Those timing parameters are met by inhibiting the CLKIN signal for a specific window during Write Cycles to the 82370 Timer Unit.

The CLKIN signal must be inhibited using external logic, as the GATE function of the 82370 timer unit is not guaranteed to totally inhibit CLKIN.

1.2 Consequences

This CLKIN inhibits circuitry guarantees proper write cycles to the 82370 timer unit.

Without this solution, write cycles to the 82370 timer unit could place corrupted data into the timer unit registers. This, in turn, could yield inaccurate results and improper timer operation.

The proposed solution would involve a hardware modification for existing systems.

1.3 Solution

A timing waveform (Figure C-3) shows the specific window during which CLKIN must be inhibited. Please note that CLKIN must only be inhibited during the window shown in Figure C-3. This window is defined by two AC timing parameters:

t_a = 9 ns

t_b = 28 ns

The proposed solution provides a certain amount of system "guardband" to make sure that this window is avoided.

PAL equations for a suggested workaround are also included. Please refer to the comments in the PAL codes for stated assumptions of this particular workaround. A state diagram (Figure C-4) is provided to help clarify how this PAL is designed.

Figure C-5 shows how this PAL would fit into a system workaround. In order to show the effect of this workaround on the CLKIN signal, Figure C-6 shows how CLKIN is inhibited. Note that you must still meet the CLKIN AC timing parameters (e.g. t_{47} (min), t_{48} (min)) in order for the timer unit to function properly.

Please note that this workaround has not been tested. It is provided as a suggested solution. Actual solutions will vary from system to system.

1.4 Long Term Plans

Intel has no plans to fix this behavior in the 82370 timer unit.

```
module Timer_82370_Fix
flag '-r2', '-q2', '-fl', '-t4', '-wl,3,6,5,4,16,7,12,17,18,15,14'
title '82370 Timer Unit CLKIN
      INHIBIT signal PAL Solution '
Timer_Unit_Fix device 'P16R6';

"This PAL inhibits the CLKIN signal (that comes from an oscillator)
"during Slave Writes to the 82370 Timer unit.
"
"ASSUMPTION:  This PAL assumes that an external system address
"             decoder provides a signal to indicate that an 82370
"             Timer Unit access is taking place. This input
"             signal is called TMR in this PAL. This PAL also
"             assumes that this TMR signal occurs during a
"             specific T-State. Please see Figure 2 of this
"             document to see when this signal is expected to
"             be active by this PAL.
"
"
"NOTE:        This PAL does not support pipelined 82370 SLAVE
"             cycles.
"
"(c) Intel Corporation 1989. This PAL is provided as a proposed
"method of solving a certain 82370 Timer Unit problem. This PAL
"has not been tested or validated. Please validate this solution
"for your system and application.
"
"Input Pins"

CLK2          pin      1; "System Clock
RESET         pin      2; "Microprocessor RESET signal
TMR           pin      3; "Input from Address Decoder, indicating
                          "an access to the timer unit of the
                          "82370.
!RDY          pin      4; "End of Cycle indicator
!ADS          pin      5; "Address and control strobe
CLK           pin      6; "PHI2 clock
W_R           pin      7; "Write/Read Signal"
nc1           pin      8; "No Connect 0"
nc3           pin      9; "No Connect 1"
GNDa          pin     10; "Tied to ground, documentation only
GNDb          pin     11; "Output enable, documentation only
CLKIN_IN      pin     12; "Input-CLKIN directly from oscillator

"Output Pins"
Q_0           pin     18; "Internal signal only, fed back to
                          "PAL logic"
CLKIN_OUT     pin     17; "CLKIN signal fed to 82370 Timer Unit
INHIBIT       pin     16; "CLKIN Inhibit signal
S0            pin     15; "Unused State Indicator Pin
S1            pin     14; "Unused State Indicator Pin

"Declarations"
```

```
Valid_ADS = ADS & CLK     ; "#ADS sampled in PHI1 of 80376 T-State
Valid_RDY = RDY & CLK     ; "#RDY sampled in PHI1 of 80376 T-State
Timer_Acc = TMR & CLK     ; "Timer Unit Access, as provided by
                            "external Address Decoder"

State_Diagram [INHIBIT, S1, S0]

state 000:      if RESET then 000
                else if Valid_ADS & W_R then 001
                else 000;

state 001:      if RESET then 000
                else if Timer_Acc then 010
                else if !Timer_Acc then 000
                else 001;

state 010:      if RESET then 000
                else if CLK then 110
                else 010;

state 110:      if RESET then 000
                else if CLK then 111
                else 110;

state 111:      if RESET then 000
                else if CLK then 011
                else 111;

state 011:      if RESET then 000
                else if Valid_RDY then 000
                else 011;

state 100:      if RESET then 000
                else 000;

state 101:      if RESET then 000
                else 000;

EQUATIONS
Q_0 := CLKIN_IN; "Latched incoming clock. This signal is used
                  "internally to feed into the MUX-ing logic"


CLKIN_OUT := (INHIBIT & CLKIN_OUT & !RESET)
           +(!INHIBIT & Q_0 & !RESET);

                        "Equation for CLKIN_OUT. This
                        "feeds directly to the 82370 Timer Unit."

END
```

82370 Timer Unit CLKIN
INHIBIT signal PAL Solution
Equations for Module Timer_82370_Fix

Device Timer_Unit_Fix

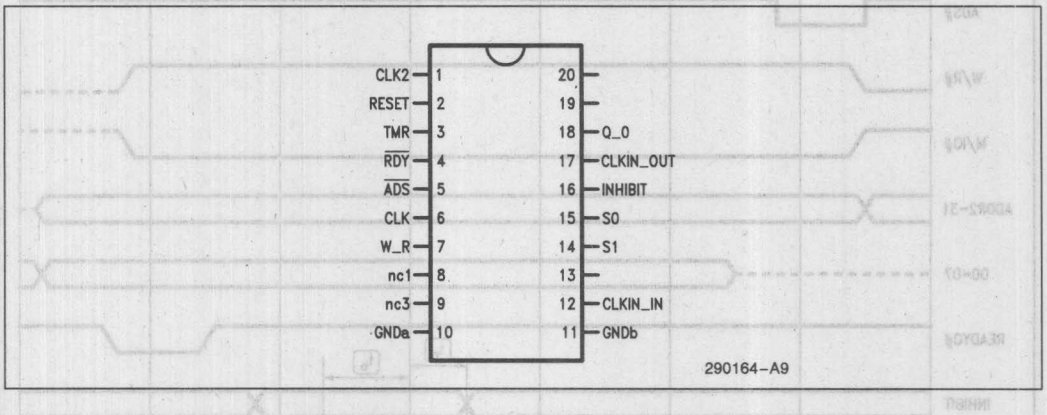
—Reduced Equations:

```
!INHIBIT := (!CLK & !INHIBIT # CLK & S0 # RESET # !S1);

!S1 := (RESET
  # INHIBIT & !S1
  # CLK & !INHIBIT & !~RDY & S0 & S1
  # !CLK & !S1
  # !S1 & !TMR
  # !S0 & !S1);


!S0 := (RESET
  # INHIBIT & !S1
  # CLK & !INHIBIT & !~RDY & S1
  #!INHIBIT & !S0 & S1
  # !CLK & !S0
  # !INHIBIT & !S0 & S1
  # S0 & !S1
  # !S1 & !W_R
  # ~ADS & !S1);


!Q_0 := (!CLKIN_IN);

!CLKIN_OUT := (RESET # !CLKIN_OUT & INHIBIT # !INHIBIT & !Q_0);
```

82370 Timer Unit CLKIN
INHIBIT signal PAL Solution
Chip diagram for Module Timer__82370__Fix

Device Timer__Unit__Fix

P16R6



end of module Timer__82370__Fix

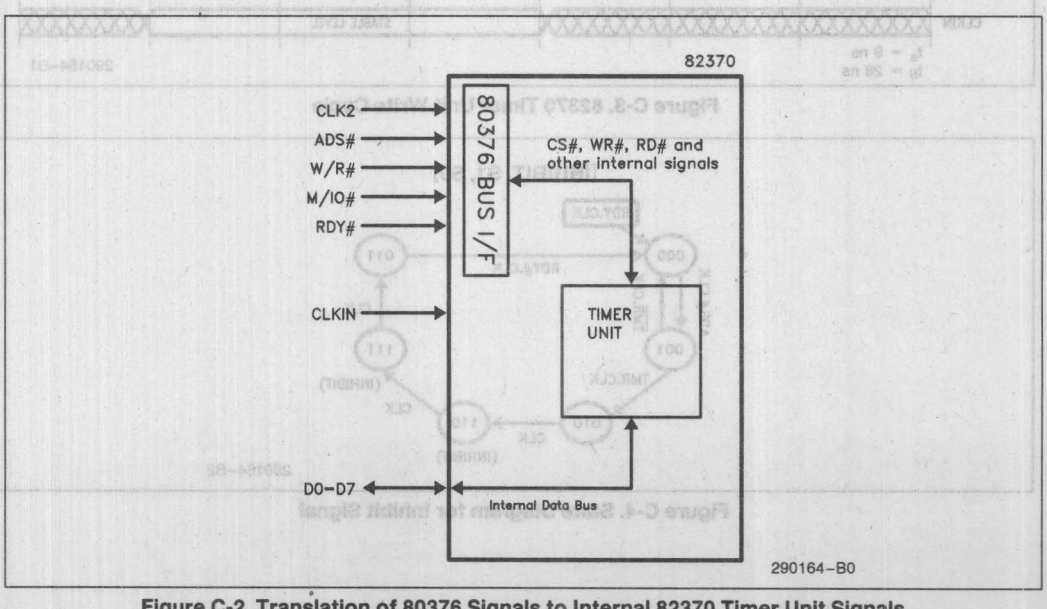


Figure C-2. Translation of 80376 Signals to Internal 82370 Timer Unit Signals

9

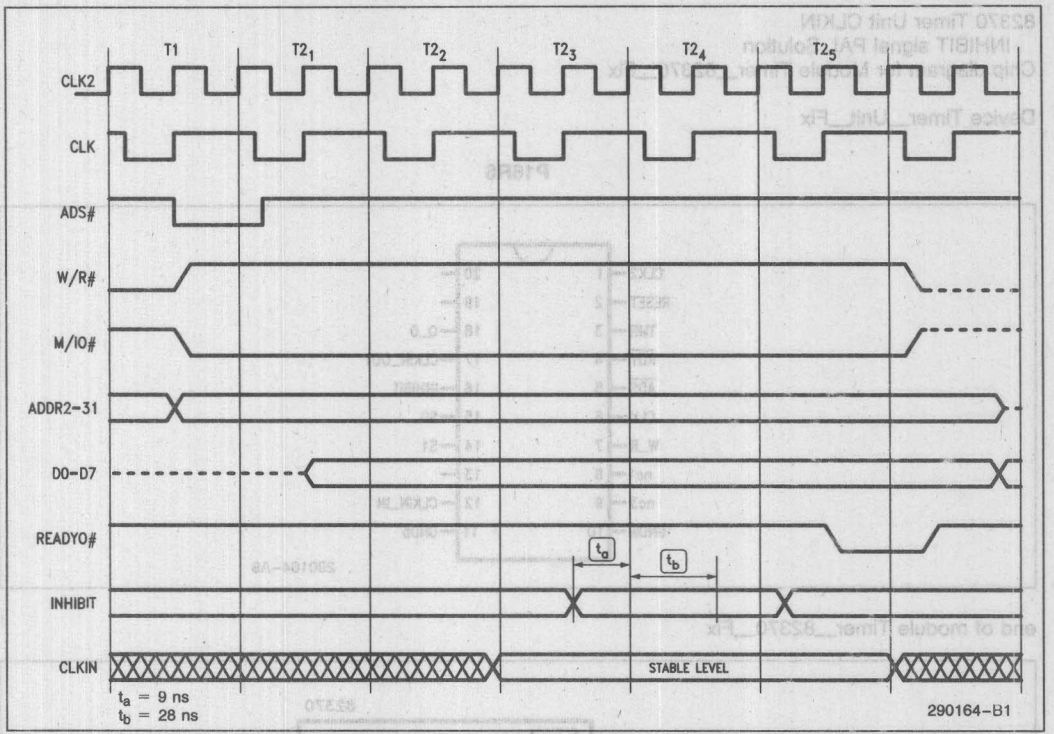


Figure C-3. 82370 Timer Unit Write Cycle

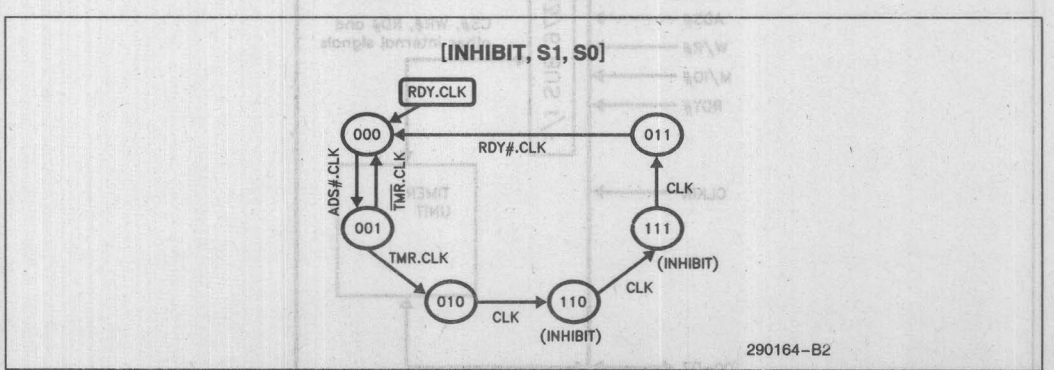
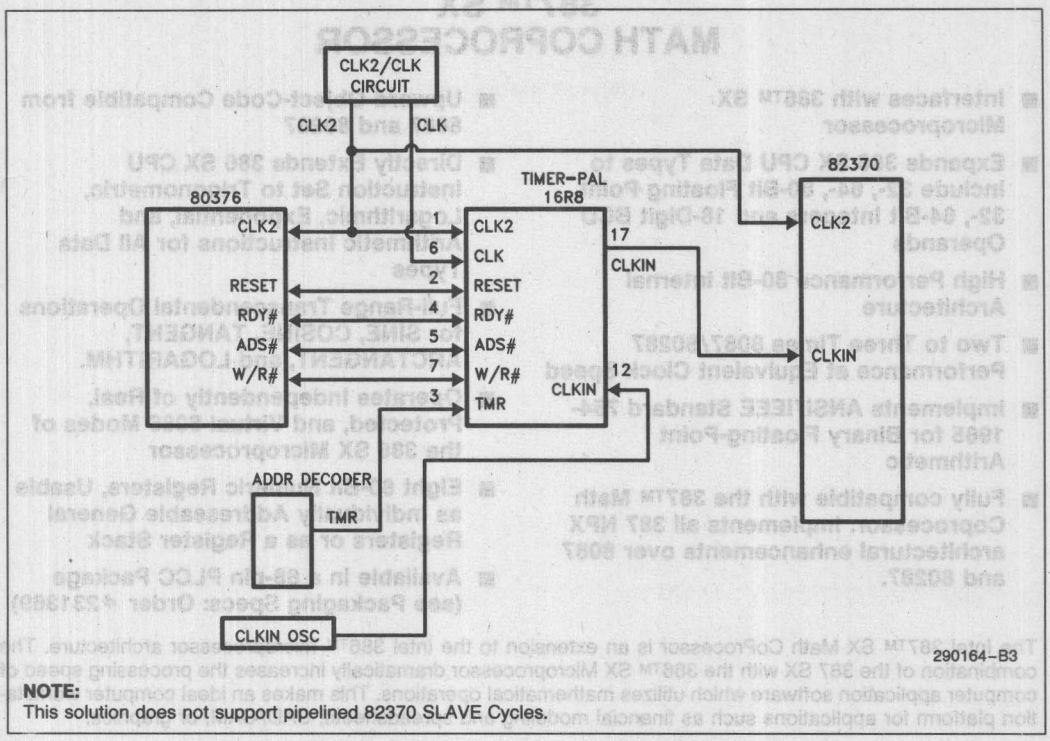


Figure C-4. State Diagram for Inhibit Signal



NOTE:
This solution does not support pipelined 82370 SLAVE Cycles.

Figure C-5. System with 82370 Timer Unit "INHIBIT" Circuitry

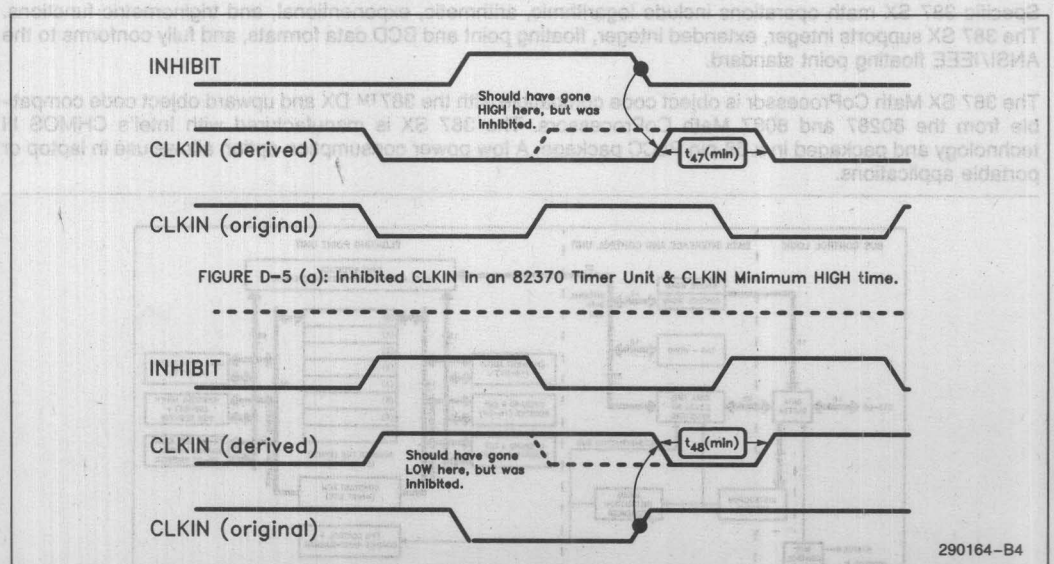


Figure C-6. Inhibited CLKIN in an 82370 Timer Unit and CLKIN Minimum LOW Time

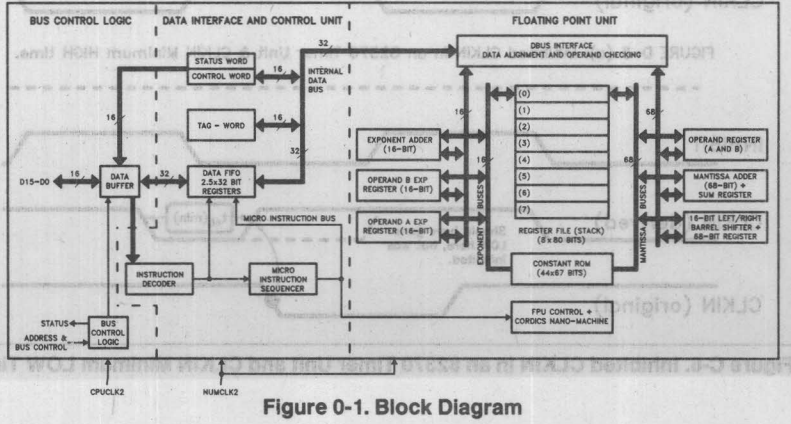
387™ SX
MATH COPROCESSOR

- **Interfaces with 386™ SX Microprocessor**
- **Expands 386 SX CPU Data Types to Include 32-, 64-, 80-Bit Floating Point, 32-, 64-Bit Integers and 18-Digit BCD Operands**
- **High Performance 80-Bit Internal Architecture**
- **Two to Three Times 8087/80287 Performance at Equivalent Clock Speed**
- **Implements ANSI/IEEE Standard 754-1985 for Binary Floating-Point Arithmetic**
- **Fully compatible with the 387™ Math Coprocessor. Implements all 387 NPX architectural enhancements over 8087 and 80287.**
- **Upward Object-Code Compatible from 8087 and 80287**
- **Directly Extends 386 SX CPU Instruction Set to Trigonometric, Logarithmic, Exponential, and Arithmetic Instructions for All Data Types**
- **Full-Range Transcendental Operations for SINE, COSINE, TANGENT, ARCTANGENT, and LOGARITHM.**
- **Operates Independently of Real, Protected, and Virtual-8086 Modes of the 386 SX Microprocessor**
- **Eight 80-Bit Numeric Registers, Usable as Individually Addressable General Registers or as a Register Stack**
- **Available in a 68-pin PLCC Package (see Packaging Specs: Order #231369)**

The Intel 387™ SX Math CoProcessor is an extension to the Intel 386™ microprocessor architecture. The combination of the 387 SX with the 386™ SX Microprocessor dramatically increases the processing speed of computer application software which utilizes mathematical operations. This makes an ideal computer workstation platform for applications such as financial modeling and spreadsheets, CAD/CAM, or graphics.

The 387 SX Math CoProcessor adds over seventy mnemonics to the 386 SX Microprocessor instruction set. Specific 387 SX math operations include logarithmic, arithmetic, exponentional, and triginometric functions. The 387 SX supports integer, extended integer, floating point and BCD data formats, and fully conforms to the ANSI/IEEE floating point standard.

The 387 SX Math CoProcessor is object code compatible with the 387™ DX and upward object code compatible from the 80287 and 8087 Math CoProcessors. The 387 SX is manufactured with Intel's CHMOS III technology and packaged in a 68-pin PLCC package. A low power consumption option allows use in laptop or portable applications.



240225-1

Figure 0-1. Block Diagram

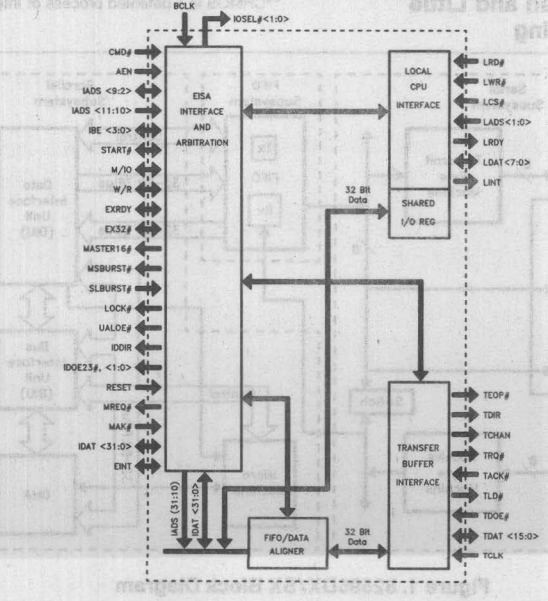
For the complete data sheet on this product, refer to the 1991 Microcommunications handbook.

September 1990
Order Number: 240225-005

82355
BUS MASTER INTERFACE CONTROLLER (BMIC)

- Designed for use in 32-Bit EISA Bus Master Expansion Board Designs
  - Integrates Three Interfaces (EISA, Local CPU, and Transfer Buffer)
- Supports 16- and 32-Bit Burst Transfers
  - 33 Mbytes/Sec Maximum Data Transfers
- Supports 32-Bit Non-Burst and Mismatched Data Size Transfers
- Supports 32-Bit EISA Addressability (4 Gigabyte)
- Two Independent Data Transfer Channels with 24-Byte FIFOs
  - Expansion Board Timing and EISA Timing Operate Asynchronously
- Supports Peek/Poke Operation with the Ability to Access Individual Locations in EISA Memory or I/O space
- Automatically Handles Misaligned Doubleword Data Transfers with No Performance Penalty
- Supports Automatic Handling of Complete EISA Bus Master Protocol
  - EISA Arbitration/Preemption
  - Cycle Timing and Execution
  - Byte Alignment
  - 1K Boundary Detection
- Supports Local Data Transfer Protocol Similar to Traditional DMA
- Supports a General Purpose Command and Status Interface
  - Local and EISA System Interrupt Support
  - General Purpose Information Transfers
  - Set-and-Test-Functions in I/O Space (Semaphore Function)
  - Supports the EISA Expansion Board ID Function
- Supports Decode of Slot Specific and General I/O Addresses
- 132-Pin JEDEC PQFP Package

82355 Internal Block Diagram



290255-1

October 1990
Order Number: 290255-003

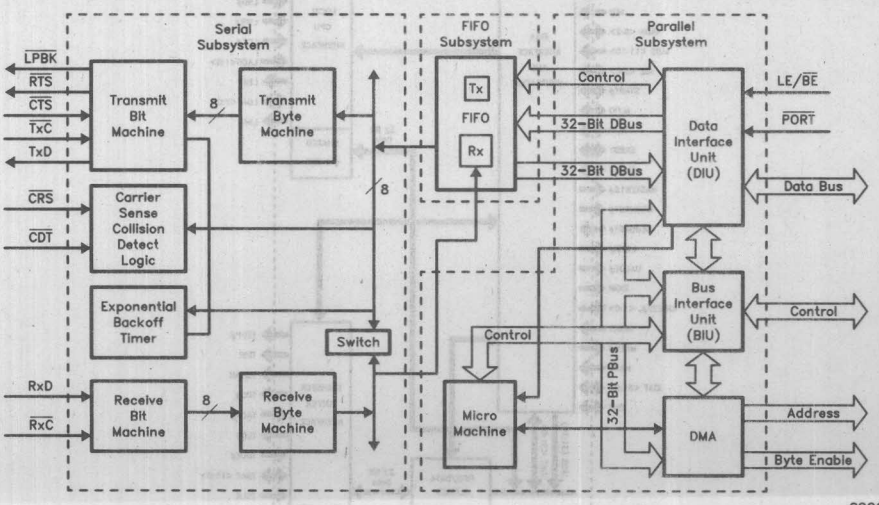
PRELIMINARY

82596DX AND 82596SX HIGH-PERFORMANCE 32-BIT LOCAL AREA NETWORK COPROCESSOR

- **Performs Complete CSMA/CD Medium Access Control (MAC) Functions—Independently of CPU**
  - **— IEEE 802.3 (EOC) Frame Delimiting**
  - **— HDLC Frame Delimiting**
- **Supports Industry Standard LANs**
  - **— IEEE TYPE 10BASE5 (Ethernet*), IEEE TYPE 10BASE2 (Cheapernet), IEEE TYPE 1BASE5 (StarLAN), and the Proposed Standards TYPE 10BASE-T and 10BASE-F**
  - **— Proprietary CSMA/CD Networks Up to 20 Mb/s**
- **On-Chip Memory Management**
  - **— Automatic Buffer Chaining**
  - **— Buffer Reclamation after Receipt of Bad Frames; Optional Save Bad Frames**
  - **— 32-Bit Segmented or Linear (Flat) Memory Addressing Formats**
- **82586 Software Compatible**
- **Optimized CPU Interface**
  - **— Optimized Bus Interface to Intel's 32-Bit 386™DX and 16-Bit 386™SX and 376™ Microprocessors**
  - **— Supports Big Endian and Little Endian Byte Ordering**
- **High-Performance 32-Bit Bus Master Interface**
  - **— 66-MB/s Bus Bandwidth**
  - **— 33-MHz Clock, Two Clocks Per Transfer**
  - **— Bus Throttle Timers**
  - **— Transfers Data at 100% of Serial Bandwidth**
  - **— 128-Byte Receive FIFO, 64-Byte Transmit FIFO**
- **Network Management and Diagnostics**
  - **— Monitor Mode**
  - **— 32-Bit Statistical Counters**
- **Self-Test Diagnostics**
- **Configurable Initialization Root for Data Structures**
- **High-Speed, 5-V, CHMOS** IV Technology**
- **132-Pin Plastic Quad Flat Pack (PQFP) and PGA Package**

  (See Packaging Spe. Order No. 231369)

386™ is a trademark of Intel Corporation
*Ethernet is a registered trademark of Xerox Corporation.
**CHMOS is a patented process of Intel Corporation.



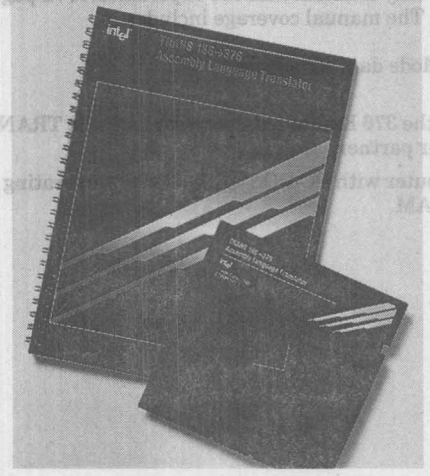
290219-1

Figure 1. 82596DX/SX Block Diagram

For the complete data sheet on this product, refer to the 1991 Microprocessor Vol. II handbook

October 1990
Order Number: 290219-003

TRANS 186 → 376 ASSEMBLY CODE TRANSLATOR



270919-1

To Order TRANS 186 → 376 Software, contact your local Intel sales office

TRANS 186 → 376 PRESERVES YOUR PROGRAMMING INVESTMENT

When your embedded application outgrows the 80C186 family, TRANS 186 → 376 is ready to help you upgrade to the 376™ Embedded Processor. TRANS 186 → 376 is a DOS-based tool to automate the translation of Intel ASM86 source code to ASM386 source code. This program can actually help protect the man-years of investment in your original 86 software.

TRANS 186 → 376 LOWERS THE 32-BIT BARRIER

TRANS 186 → 376 accepts 16-bit source code written for any member of the 8086/8088 and 80C186/80C188 families. The output source code, with its 32-bit offsets, is suitable for Protected Mode execution on the 376 Embedded Processor or any 386™, 386SX, or 486™ microprocessor. The time you save by recycling your software can be applied toward system enhancements.

You control TRANS 186 → 376 operation from either the DOS command line or a control file. Major control switches cover:

- Choice of FLAT model or LARGE16 memory environment
- Redefinition of segments
- Optional 32-bit data declaration

TRANS 186 → 376 translates your routines on a line-by-line basis, converting as much code as possible. Whenever the tool does not have enough information to make conversions, it highlights the code section with messages, alerting you to edit by hand. TRANS 186 → 376 can write the ASM86 source code as comments in the ASM386 source file for side-by-side comparison.

9

* PC AT and PC-DOS are trademarks of IBM.
**MS-DOS is a trademark of Microsoft Corporation.

November 1990
Order Number: 270919-001

intel

TRANS 186 → 376 ASSEMBLY CODE TRANSLATOR

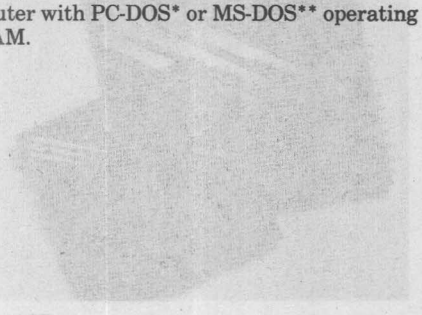
TRANS 186 → 376 COMPLEMENTS OTHER DEVELOPMENT TOOLS

Upon request, TRANS 186 → 376 generates a build file for the Intel System Builder, BLD386. This allows you to get your software running with only minimal BLD386 experience. A 72-page manual accompanies the TRANS 186 → 376 tool. The manual coverage includes:

- Practical tips on the overall conversion process
- Initializing the CPU and generating Protected Mode data structures
- Producing code for emulators and debuggers

Your 80C186 experience can release the power of the 376 Embedded Processor with the TRANS 186 → 376 Assembly Language Translator as your partner.

System requirements: PC AT* or compatible computer with PC-DOS* or MS-DOS** operating system version 3.0 or later, hard disk, and 512K RAM.



376™ Development Support Tools

10

10 376™ Development Support Tools

INTEL386™/i486™ FAMILY DEVELOPMENT SUPPORT

280808-1

COMPREHENSIVE DEVELOPMENT SUPPORT FOR THE INTEL386™/i486™ FAMILIES OF MICROPROCESSORS

The perfect complement to the Intel386™ and i486™ microprocessor family is the optimum development solution. From a single source, Intel, comes a complete, synergistic hardware and software development toolset, delivering full access to the power of the Intel386 and i486 microprocessor family architectures.

Intel development tools are easy to use, yet powerful, with contemporary user interface techniques and productivity boosting features such as symbolic debugging. And you'll find Intel first to market with the tools needed to start development, and with lasting product quality and comprehensive support to keep development on-track.

If what interests you is getting the best product to market in as little time as possible, Intel is the choice.

*AboveBoard, i486, Intel386, 386 DX, 386 SX, 376, 387, ICE, and iPAT are trademarks of Intel Corporation.
VAX, MicroVAX and VMS are registered trademarks of Digital Equipment Corporation.

November 1990
Order Number: 280808-005

FEATURES

- Comprehensive support for the full 32 bit Intel 386 and i486 microprocessor architectures—includes protected mode, 4 gigabyte physical memory addressing, and i486 microprocessor on-chip cache and numerics
- Standard windowed interface that is common across Intel debug tools and architectures
- Source line display and symbolics allow debugging in the context of the original program
- Intel high-level languages provide architectural extensions for manipulating hardware directly without assembly language routines
- A common object code format (Intel OMF386™) supports symbolic debug and permits the intermixing of modules written in various languages—Intel's assembler, C, PL/M, and FORTRAN
- A common OMF386 permits compilers and assembler to seamlessly operate with in-circuit and software debug tools
- ROM-able code is output directly from the language tools, significantly reducing the effort necessary to integrate software into the final target system
- Extensive support for the Intel family of math coprocessors
- Operation in DOS IBM PC AT*, PS/2 Model 60 and 80, or compatible) and VAX/VMS* hosted environments

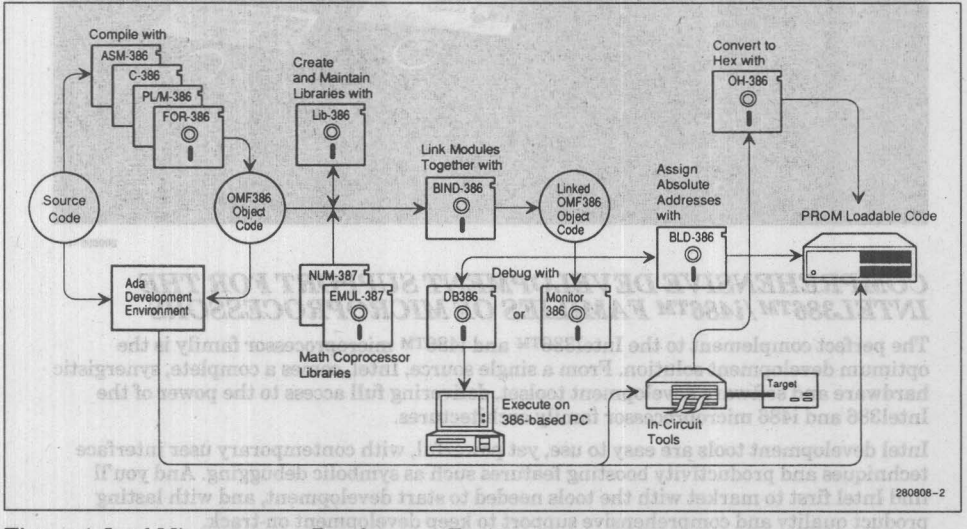


Figure 1: Intel Microprocessor Development Environment

FEATURES

ASM 386™/i486™ MACRO ASSEMBLER

Intel's ASM 386™ is a "high-level" macro assembler for the Intel386 Family. ASM 386 offers many features normally found only in high-level languages. The macro facility in ASM 386 saves development time by allowing common program sequences to be coded only once. The assembly language is strongly typed, performing extensive checks on the usage of variables and labels.

Other Intel ASM 386 features include:

- "High-level" assembler mnemonics to simplify the language
- Structures and records for data representation
- Support for Intel's standard object code format for source-level symbolic debug, and for linking object modules from other Intel386 and i486 microprocessor languages
- Full support for processor and math coprocessor instruction sets
- A "MOD486" switch for support of the i486 microprocessor instructions
- 16 bit or 32 bit address overrides
- Supports development for Virtual 86, Real, 286 Protected, and 386 Protected modes

iC386™/i486™ COMPILER

Intel's iC-386 compiler provides special features for architectural support and code efficiency, for ease of use, and for compatibility with other Intel development tools.

The iC-386 compiler produces code for Intel386 and i486™ processors from C source files, and conforms to the 1989 ANSI standard (ANS X3.159-1989) for the C programming language.

Key Intel iC-386 features include:

- Controls to tailor the compilation for each step of your application development process
- In-line versions of many ANSI-standard library functions
- Uses expanded memory (LIM Version 3.0 and higher)
- Object code (including supplied run-time libraries) suitable for ROM
- Three different levels of optimization
- A choice of three segmentation memory models (small, compact, and flat) to create compact and efficient code
- Object code that takes advantage of the on-chip cache of the i486 processor
- In-line processor-specific functions and time-saving macros that provide access to the special features of the Intel386 and i486 processors
- In-line floating-point instructions for the 387™ numerics coprocessor and i486 processor floating-point unit
- Time-saving macros and functions to help assembly language routines interface with Intel's high-level programming languages
- The standard C run-time library plus libraries for floating-point support and the iRMX® III C interface library
- An easy interface to Intel's non-C programming languages, along with object module compatibility between Intel C and non-C compilers
- Support for source-level debugging using the Intel DB-386 Software Debugger
- Programming with subsystems, allowing mixed segmentation memory models
- Extensions to the 1989 ANSI C standard for compatibility with previous versions of Intel C

The iC-386 libraries contain over 200 functions for use in iC-386 programs. The libraries and header files make development of iC-386 applications easier by providing:

- Fast and efficient functions for common programming tasks
- Interfaces to standard and custom execution environments
- Built-in versions of some functions

PL/M386™/i486™ COMPILER

Intel's PL/M-386 is a structured high-level system implementation language for the Intel386/i486 Families. PL/M-386 supports the implementation of protected operating system software by providing built-in procedures and variables to access the Intel386/i486 architectures.

For efficient code generation, PL/M-386 features four levels of optimization, a virtual symbol table, and four models of program size and memory usage.

FEATURES

Other Intel PL/M-386 features include:

- The ability to define a procedure as an interrupt handler as well as facilities for generating interrupts
- Direct support of byte, half-word, and word input and output from microprocessor ports
- Upward compatibility with Intel PL/M-286 and PL/M-86 source code
- A "MOD486" compiler switch for i486 microprocessor instruction generation

PL/M-386 combines the benefits of a high-level language with the ability to access the Intel386 architecture. For the development of systems software, PL/M-386 is a costeffective alternative to assembly language programming.

FORTRAN 386™/i486™ COMPILER

Intel's FORTRAN-386 compiler is a cross-compiler that supports the entire Intel386 family of components and i486 (when operating in the 386 chip mode) microprocessors.

FORTRAN-386 features high-level support for floating-point calculations, transcendentals, interrupt procedures, and run-time exception handling. Specifically, the FORTRAN-386 language is a superset of the language described in the ANSI Fortran 77 standard. The additions to that standard include the Department of Defense (DOD) extensions, extensions that support programs written for the ANSI Fortran 66 standard, and extensions that support the 386 microprocessor and 80387/80387DX/80387SX math coprocessors.

To aid in the development and debugging process, the compiler generates warning and error messages and an optional listing file. The listing file can include symbol cross-reference tables and a listing of the generated 386 microprocessor assembly-language instructions. Library routines are reentrant and ROMable.

Other Intel FORTRAN-386 compiler features include:

- Object code can be configured to reside in either RAM or ROM
- The program code can be optimized for execution speed or memory size
- Source-level debugging is supported via the rich symbolics provided in the object module format (Intel OMF386)
- Support for the proposed REALMATH IEEE floating point standard

RLL 386™/i486™ RELOCATION, LINKAGE, AND LIBRARY TOOLS

The RLL 386™ relocation, linkage, and library tools are a cohesive set of utilities featuring comprehensive support of the full Intel386™/i486™ architectures. RLL-386 provides for a variety of functions—from linking separate modules, building an object library, or linking in 387™ support, to building a task to execute under protected mode or the multi-tasking, memory protected system software itself. Specifically, RLL-386 supports loadable, linkable, and bootloadable Intel object module formats; and supports all segmentation models, including FLAT. Map, librarian, and conversion (for outputting hex format code for PROM programming) utilities are included.

EMUL387, NUM387 NUMERICS SUPPORT LIBRARIES

Intel's EMUL-387 and NUM-387 Numerics Libraries fully support the 80387/80387DX/80387SX math coprocessors and the i486 internal math coprocessor—whether an actual math coprocessor is used in the final system or not.

For 386 microprocessor based applications without a math coprocessor, EMUL-387, a numerics software emulator, will execute instructions as though the coprocessor were present. Its functionality is identical to that of the math coprocessor. It is ideal for prototyping and debugging floating-point application software independent of hardware. Further, this permits portability of application code regardless of the presence of math coprocessor hardware in target systems.

For applications with a math coprocessor, NUM-387 numerics support library provides Intel's ASM 386, C-386, PL/M-386, and FORTRAN-386 language users with enhanced numeric data processing capability. With the library, it is easy for programs to do floating point arithmetic. Programmers can bind in library modules to do trigonometric, logarithmic and other numeric functions, and the user is guaranteed accurate, reliable results for all appropriate inputs.

FEATURES

Intel's NUM-387 support library is a collection of four functionally distinct libraries:

- Common elementary function library routines perform algebraic, logarithmic, exponential, trigonometric, and hyperbolic operations on real and complex numbers, as well as real-to-integer conversions; the routines extend the ranges of the coprocessor instructions
- Initialization library routines set up the numerics processing environment for 80386 microprocessor based systems with an 80387/80387DX/80387SX or true software emulator
- Decimal conversion library routines convert floating-point numbers from one 80387/80387DX/80387SX binary storage format to another, or from ASCII decimal strings to 80387/80387DX/80387SX binary floating-point format and vice versa
- Exception handling library routines make writing numerics exception handlers easier

All support library modules are in 80386 microprocessor object module format (Intel OMF-386) so they can be linked with the object output of any Intel language. All routines are reentrant and ROMable.

By using Intel's NUM-387, the user not only saves software development time, but is guaranteed that the numeric software meets industry standard (ANSI/IEEE standard for binary floating point arithmetic, 754-1985) and is portable—software investment is maintained.

FEATURES

ONCE-386

If you have a surface mount Intel386 SX microprocessor design using 100 pin PQFP parts, Intel ICE emulators now have "On-Circuit Emulation" (ONCE™) capability. With your part surface mounted, the ICE-386 SX emulator cabling clamps over the part, tri-stating the component, and allowing the emulator to operate. This allows you to debug manufactured boards without resoldering.

REM-386

Designed to enhance your existing ICE-386 DX 25 and ICE-386 DX 33 emulators, the REM-386 DX Expansion board adds 2 MB of expanded memory.

INTEL386™/i486™ FAMILY IN-CIRCUIT TOOLS

In-Circuit Emulators

Intel386 Family in-circuit emulators embody exclusive technology that gives access to internal processor states that are accessible in no other way. Intel386 microprocessors fetch and execute instructions in parallel, with fetched instructions not necessarily executing in order of input. Because of this, an emulator without this access to internal processor states is prone to error in determining what actually occurred inside the microprocessor. With Intel's exclusive technology, Intel386 Family emulators are one hundred percent accurate. In addition, internal access comes without signal buffer interference of processor timing. Operation is non-intrusive (zero wait-state).

Other features of Intel386 Family in-circuit emulators include:

- Unparalleled support of the Intel386 architecture, notably the native protected mode
- Emulation at clock speeds to 33 MHz, and full featured trigger and trace capabilities
- Convertible using removable probes to support any of the Intel386 microprocessors—80386DX, 80386SX, and 80376 microprocessors

With symbolic debugging, memory locations can be examined or modified using symbolic references to the original program, such as procedure or a variable names, line numbers, or program labels. Source code associated with a given line number can be displayed, as can the type information of variables, such as byte, word, record, or array. Microprocessor data structures, such as registers, descriptor tables, and page tables, can also be examined and modified using symbolic names. The symbolic debugging information for use with Intel development tools is produced by Intel OMF386 compatible languages.

ICE™-486 IN-CIRCUIT EMULATOR

The ICE-486 In-circuit Emulator is the world's leading tool for debugging software and hardware designs based on the Intel i486 family of microprocessors. The ICE-486 emulator features real-time emulation at speeds up to 33 MHz. The standard high- level symbolic debug capability saves valuable development time. The flexible breakpoint capability and 8K deep trace buffer provide power to identify and solve even the toughest hardware and software bugs. The emulator also provides 2 MB expansion memory to debug large programs. It is designed to work with the rich array of software development tools optimized for creating 32-bit applications.

In-Circuit Debugger

Intel's ICD-486 represents a new generation of in-circuit emulation technology. From the inventor of the microprocessor comes a development tool that delivers complete access to the i486 architecture. ICD-486 is the first development tool which allows users to debug high speed, cached applications at the full speed of the target processor. ICD-486 embodies exclusive technology, giving users symbolic access to the internal processor states that would not be accessible in any other way. With Intel;s exclusive technology, users can be assured that the ICD-486 provides complete accuracy when debugging cached applications in real-time.

Other Intel ICD-486 features include:

- Real-time emulation at the full speed of the i486 microprocessor
- Full support for the i486 on-chip caching and numerics
- Ability to set up to 16 software breakpoints and four hardware breakpoints on execution addresses, data writes, or data accesses
- Full symbolic information to display and modify all registers of the i486 microprocessor

FEATURES

SOFTWARE DEBUGGER

Intel's DB386™ is an on-host software execution environment with source-level symbolic debug capabilities for object modules produced by Intel's assembler and high-level language compilers. For the DOS hosted version, this software debug environment allows 386 microprocessor code to be executed and debugged directly on a 386 DX or 386 SX microprocessor based PC, without any additional target hardware required. With Intel's standard windowed human interface, users can focus their efforts on finding bugs rather than spending time learning and manipulating the debug environment.

For the VMS* hosted version, the debugger works in conjunction with an extensive 386 microprocessor software instruction simulator included with the product. This simulator simulates the 386 microprocessor in "flat" mode, 387, 8259A and 8254 interrupt controller and timer chips, supports map memory up to 4 gigabytes, and provides complex break, trace, and profiling support.

FEATURES

Other Intel DB386™ features include:

- A run-time interface allows protected-mode 386 microprocessor programs to be executed directly on a 386 DX or 386 SX microprocessor based PC
- Drop-down menus make the tool easy to learn for new or casual users. A command line interface is also provided for more complex problems
- Watch windows (which display user-specified variables), trace points, and breakpoints (including fixed, temporary, and conditional) can be set and modified as needed, even during a debug session
- The user can browse source and callstacks, observe processor registers, and access watch window variables by either the pull down menu or by a single keystroke using the function keys
- An easy-to-use disassembler and single-line assembler speeds the debug process
- The user need not know whether a variable is an unsigned integer, a real, or a structure—the debugger uses the wealth of typing information available in Intel languages to display program variables in their respective type formats
- DB-386 supports the i486 microprocessor when operated in the 386 microprocessor mode

MON386 TARGET RESIDENT SOFTWARE DEBUGGER

Intel's MON-386 is a hosted or unhosted target resident software debugger for the 386 DX and 386 SX-based systems. MON-386 provides program execution control and symbolic processor and memory interrogation and modification. Hardware and software breakpoints can be set at symbolic addresses and program execution can be single-stepped through assembly level or high-level language instructions.

Other Intel MON-386 features include:

- Debug procedures (user-definable sequences of MON-386 commands) enable users to define macro commands that would otherwise take several lines of command entries to perform the same function
- A disassembler/single line assembler allows users to display memory and patch memory with 80386/80387 mnemonics

MON-386, used in conjunction with Intel single board computers iSBC® 386/22 and iSBC 386/116, or other customer designed systems, can debug software before a functional prototype of the target system is available.

Intel's MON-386 can be used for i486 microprocessor development when the component is run in the 386 microprocessor mode of operation.

iPAT-386™ PERFORMANCE ANALYSIS TOOL

Intel's iPAT-386™ performance analysis tool provides analysis of real-time software executing on a 386-based target system. With iPAT-386, it is possible to speed-tune applications, optimize use of operating systems, determine response characteristics, and identify code execution coverage.

By examining iPAT-386 histogram and tabular information about procedure usage for critical functions (with the option of including interaction with other procedures, hardware, the operating system, or interrupt service routines) performance bottlenecks can be identified. With iPAT-386 code execution coverage information, the completeness of testing can be confirmed.

Intel's iPAT-386 provides real-time analysis up to 20 MHz, performance profiles of up to 125 partitions, and code execution coverage analysis over 252K. The iPAT-386 target probe is used with the same iPAT base module supporting 80286, 80186, and 8086 development. The iPAT-386 system can be used independently or piggy-backed with Intel386 in-circuit emulator tools.

WORLDWIDE SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support and on-site service.

Intel also offers a Software Support package which includes technical software information, telephone support, automatic distribution of software and documentation updates, access to the "ToolTalk" electronic bulletin board, "*iComments*" publication, remote diagnostic software, and a development tools troubleshooting guide.

FEATURES

PRODUCT SUPPORT MATRIX

Product	Component				Host	
	i486™	386™ DX	386™ SX	376™	DOS 3.x	VMS 5.1+
ASM-386 Macro Assembler	✓	✓	✓	✓	✓	✓
iC-386 Compiler	✓	✓	✓	✓	✓	✓
PL/M-386 Compiler	✓	✓	✓	✓	✓	✓
FORTRAN-386 Compiler	✓	✓	✓	✓	✓	✓
RLL-386 Relocation, Linkage, Library, Support Tools	✓	✓	✓	✓	✓	✓
NUM-387 Libraries	✓	✓	✓	✓	✓	✓
EMUL-387 Libraries	NA	✓	✓	✓	✓	✓
In-circuit Emulators		✓	✓	✓	✓	
In-circuit Debugger	✓				✓	
DB-386 Software Debugger	✓	✓	✓	✓	✓	
MON-386 Target Level Software Debugger		✓	✓	✓	✓	
iPAT-386 Performance Analysis Tool		✓			✓	

ORDERING INFORMATION

386™/i486™ FAMILY DOS HOSTED DEVELOPMENT KIT ORDER CODES

DKIT386C	Compiler Software Development Kit (see following content list). Also supports i486 microprocessor
DKIT386CS	C Compiler Software Development Kit w/ one year Gold Software Support. Also supports i486 microprocessor.
DKIT386CIDX	C Compiler Software Development Kit w/ ICE386 DX 33 MHz In-circuit Emulator and 2 MB AboveBoard™
DKIT386CIDXS	Same as above w/ one year Hardware and Gold Software Support
pDKIT386CISX	C Compiler Software Development Kit w/ ICE386 SX 20 MHz In-circuit Emulator and 2 MB Above Board
pDKIT386CISXS	Same as above w/ one year Hardware and Gold Software Support
pDKIT386CI376	C Compiler Software Development Kit w/ ICE376 16 MHz In-circuit Emulator and 2 MB Above Board
pDKIT386CI376S	Same as above w/ one year Hardware and Gold Software Support

The Intel Basic Software Development Kit for the DOS hosted environment includes:

iC386 compiler
ASM386 assembler
RLL386 relocation linker and locator (builder/binder)
NUM387 numerics library
EMUL387 math coprocessor emulator library
DB386 software debugger
OMF386LOAD loader development object module format documentation

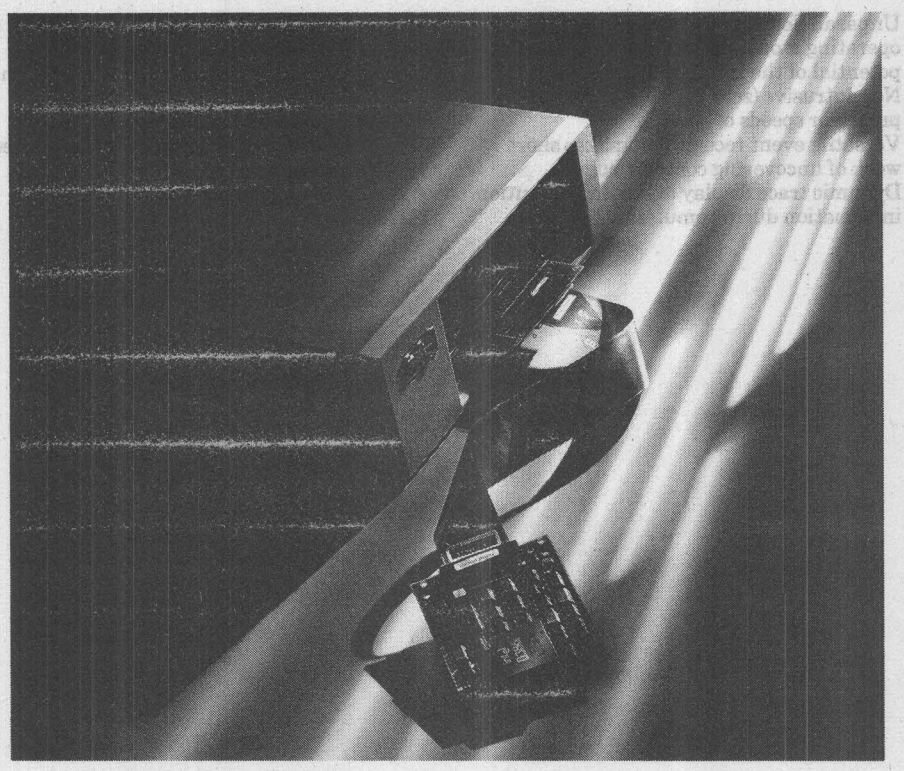
386™/i486™ FAMILY VAX AND MICROVAX/VMS HOSTED DEVELOPMENT KIT ORDER CODES*

MVVSC386KIT	MicroVAX/VMS C386 compiler, RLL386 relocation linker and locator, ASM386 assembler, DB386 software debugger
MVVSP386KIT	MicroVAX/VMS PL/M386 compiler, RLL386, ASM386, DB386
MVVSF386KIT	MicroVAX/VMS FORTRAN386 compiler, RLL386, ASM386, DB386
VVSC386KIT	VAX/VMS C386, RLL386, ASM386, DB386
VVSP386KIT	VAX/VMS PL/M386, RLL386, ASM386, DB386
VVSF386KIT	VAX/VMS FORTRAN386, RLL386, ASM386, DB386

ADDITIONAL 386™/i486™ FAMILY DEVELOPMENT TOOL ORDER CODES

ICD48625D	25 MHz In-circuit Debugger for the i486 microprocessor
ICD486CON33D	ICD48625D with a prepaid upgrade to 33 MHz
iPATCORE	iPAT Performance Analysis Tool base unit
iPAT386DOS	iPAT 80386 probe kit including PC-DOS 3.x software, requires iPATCORE

INTEL386™ FAMILY IN-CIRCUIT EMULATORS



280850-1

ACCURATE AND SOPHISTICATED EMULATION FOR THE INTEL386™ FAMILY OF MICROPROCESSORS

Intel386™ In-circuit Emulators are the cornerstone of the optimum development solution for the Intel386 Family of microprocessors. From the inventor of the microprocessor comes a development tool that delivers absolute access to the sophistication of the architecture in a way that only Intel can.

Productivity boosting features such as symbolic debugging make Intel386 emulators easy to use and powerful. Intel product quality and world class technical support and service minimizes the "downtime" incurred in resolving problems. And your investment in development tools is protected via interchangeable probes for the 80386 DX, 80386 SX, and 80376 microprocessors.

Maximize your productivity with Intel development tools. Reduced time to market and increased market acceptance for your microprocessor-based product are the benefits when Intel is the choice.

*HP9000 is a trademark of Hewlett Packard.
ICE, iPAT, Above Board, Intel386, 386 DX, 386 SX, and 376 are trademarks of Intel Corporation.
IBM, PC AT, PS/2 are registered trademarks of International Business Machines Corporation.
GPIB-PCII, GPIB-PCIIA, and MC-GPIB are trademarks of National Instruments Corporation.

December 1990
Order Number: 280850-004

FEATURES

INTEL ICE™-386 FAMILY IN-CIRCUIT EMULATOR FEATURES

- Unparalleled support of all of the Intel386 operating modes opens the door to the full potential of the Intel386 architecture
- Non-intrusive (zero wait-state) emulation to processor speeds of 33 MHz
- Versatile event recognition makes short work of uncovering complex bugs
- Dynamic trace display of bus and execution information during emulation
- A comprehensive software development system creates the most complete development environment available from a single vendor
- A companion performance analysis tool provides analysis of software for optimized performance and reliability
- Available on Hewlett-Packard HP9000 UNIX*.

FEATURES

100% ACCURATE EMULATION

Intel386 Family In-circuit Emulators embody technology that accesses internal processor states that are otherwise invisible. Intel386 microprocessors fetch and execute instructions in parallel; fetched instructions are not necessarily executed in any order. Because of this, an emulator without this capability is prone to error in determining what actually occurs inside the microprocessor. With Intel's technology, an Intel386 In-circuit Emulator displays execution history with one hundred percent accuracy and in real-time.

OPENING THE DOOR TO PROTECTED MODE

The Intel386 family of In-circuit Emulators opens the door to the full potential of the architecture with unparalleled support of protected mode. Not only does the emulator display and modify task state segments and global, local, and interrupt descriptor tables (with symbolic access to all descriptor components like privilege level and segment type), but emulator functions are sensitive to the operating mode of the processor, greatly improving ease of use.

The Intel386 family of In-circuit Emulators supports all aspects of protected mode addressing, including paged virtual memory. Processor tables are used to automatically translate virtual addresses to linear and physical addresses. Physical addresses can be translated to symbolic references to indicate the module, procedure, or data segment accessed. And when debugging a memory management system, components of the page table and directory can be displayed and modified.

FLEXIBLE AND VERSATILE EVENT RECOGNITION

Flexibility and versatility in event recognition makes short work of uncovering the most complex bugs. Bus event recognition circuitry may be used to trigger on specific or masked data input, output, read, written, or fetched at a physical address or range of addresses. Or on-chip debug registers may be used to trigger on virtual, linear, or symbolic addresses being executed, accessed, or written.

Versatility shows in other triggering options—upon a task switch, an external signal from another emulator or a logic analyzer, multiple occurrences of an event, a full trace buffer, halt or shutdown cycles, or interrupt acknowledge. And up to four sequential event triggers can be combined with a high-level construct.

The Intel386 family of In-circuit Emulators continuously captures all bus activity and, as an option, execution information, into a trace buffer of 4 K frames with PRE, POST, and CENTERED collection modes. The contents of the trace buffer can be displayed during full speed emulation in either execution cycle or machine-level instruction formats. Symbolic information can optionally be included in the trace display. A third trace display, the current chain of procedure calls, can be displayed when emulating high-level language programs.

SPEEDING DEVELOPMENT WITH SYMBOLICS

Intel386 processor data structures, such as registers, descriptor tables, and page tables, can be examined and modified using symbolic names. And with the symbolic debugging information that is a feature of Intel languages, memory locations can be accessed using symbolic references to the source program (such as a procedure and variable names, line numbers, or program labels) rather than via cumbersome virtual, linear, or physical addresses. The type information of variables (such as byte, word, record, or array) can also be displayed.

ACCESSING THE POWER

The power of the Intel386 In-circuit Emulator is reflected in the sophisticated user interface. Refined for ease-of-use, the command line interface contains many features to boost productivity and customize functionality.

On-line help, a syntax menu, command line editing, command history, and error message query promote ease of learning and use. I/O redirection and the ability to escape to the host operating system provide versatility for the power user. Customized procedures with variables and literal definitions can be created to assist in debugging or for manufacturing test or field service applications.

FEATURES

ADDITIONAL FEATURES

The Intel386 In-circuit Emulator can be combined with a variety of devices. I/O lines synchronize emulation starts and triggers with external tools such as a logic analyzer or another emulator. An optional Time Tag Board synchronizes multiple Intel386 emulators and records timestamp information in the trace buffer with 20 nanosecond resolution. An Optional Clips Pod allows 8 user defined data lines to be captured and displayed in the trace. The bus isolation board buffers the emulation processor from faults in an untested target. And with the Stand-Alone Self-Test board the emulator can be used to debug software before the target system is functional, as well as execute confidence tests.

THE INVESTMENT PICTURE

As designs move from one Intel386 Family processor to another, the reinvestment cost is limited to probes that adapt the emulator base to the specific processor. Beside cost savings, migration from one processor to another is accomplished with minimum disruption in the engineering environment, as the same command language applies to the entire emulator family.

FEATURES

SOFTWARE COMPLETES THE SYSTEM

Intel wraps a comprehensive software development system around the emulator to deliver the most complete development environment available from a single vendor. Like the emulator, Intel's software development system supports every aspect of the Intel386 architecture.

Overlooked at times is the fact that a significant part of developing a system is making sure the code works. Intel languages and software debugger integrate seamlessly with the Intel386 emulator and provide the symbolics so important for efficient debugging. By using Intel software tools with the Intel386 emulator the full power of Intel development solution can be utilized.

The software development system offers a broad choice of languages with object code compatibility so performance can be maximized by using different languages for specialized, performance critical modules. Architectural extensions in the high-level languages allows hardware features such as interrupts, input/output, or flags to be controlled directly, avoiding the tediousness of coding assembly language routines.

Intel's software portfolio includes a unique, sophisticated, and very powerful system builder, simplifying the generation of protected mode systems. To further reduce the effort necessary to integrate software into the final target configuration, Intel tools produce ROM-able code directly from the development system.

OPTIMIZING PERFORMANCE AND RELIABILITY

A companion performance analysis tool, iPAT™-386, provides analysis of real-time software executing on 80386-based target systems. With iPAT-386, it is possible to speed-tune applications, optimize use of operating systems, determine response characteristics, and identify code execution coverage. And iPAT-386 can be used in conjunction with an Intel386 in-circuit emulator to control test conditions.

WORLD CLASS, WORLDWIDE SERVICES

Augmenting the Intel386 Family development tools is a full array of seminars, classes and workshops; on-site consulting services; field application engineering expertise; telephone hotline support; and software and hardware maintenance contracts.

ICE™-386 DX 33 MHz SPECIFICATIONS AND REQUIREMENTS

HOST SYSTEM REQUIREMENTS

The user supplied host system can be either an IBM® PC AT® or Personal System/2® Model 60. Host system requirements to run the emulator include the following:

- DOS version 4.0 or Hewlett Packard HP9000 UNIX
- 640 Kbytes of RAM in conventional memory
- An Above™ board with 1 megabyte of RAM configured in expanded memory mode, EMM.SYS software version 3.2
- A 20 MB hard disk
- A serial port or the National Instruments GPIB-PCII™, GPIB-PCIIA™, or MC-GPIB™ board
- A math coprocessor if either the optional time tag board is used or if a math coprocessor resides on the target system

ELECTRICAL CHARACTERISTICS

100–120V or 220–240V selectable
50–60 Hz
2 amps (AC max) @ 120V
1 amp (AC max) @ 240V

ENVIRONMENTAL CHARACTERISTICS

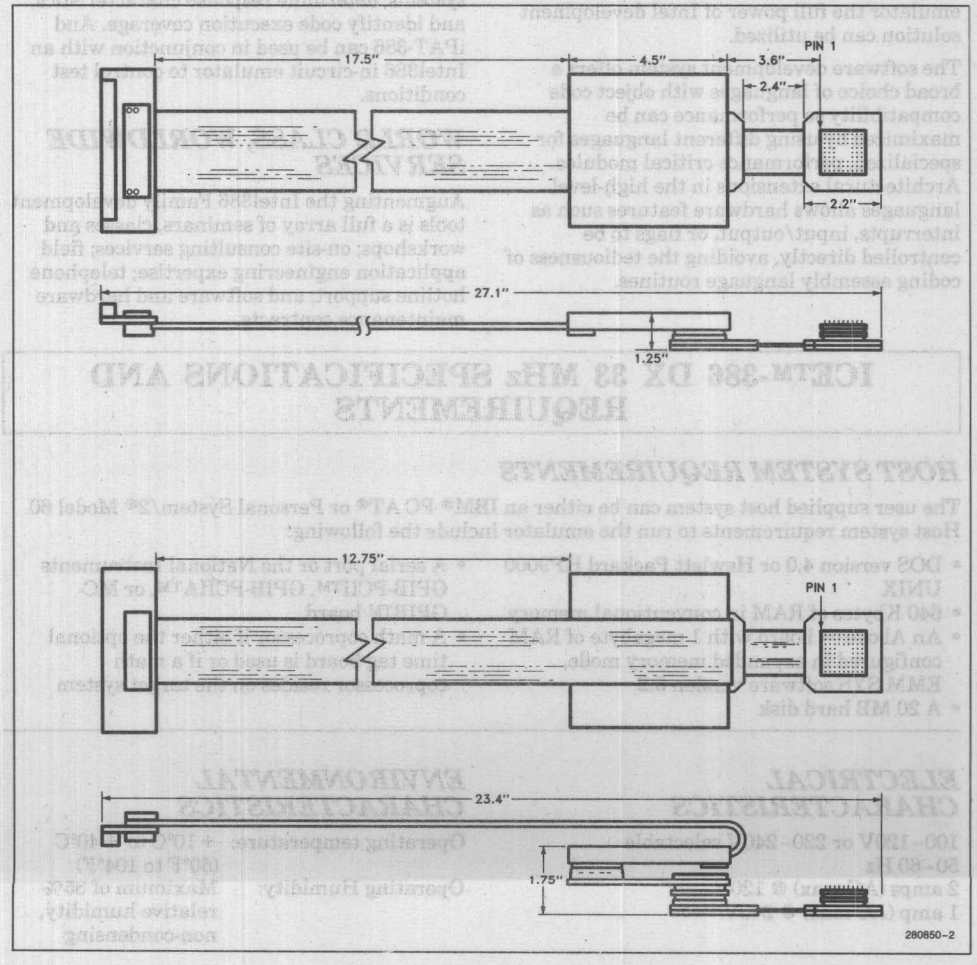
Operating temperature:	+10°C to +40°C (50°F to 104°F)
Operating Humidity:	Maximum of 85% relative humidity, non-condensing

ICE™-386 DX 33 MHz SPECIFICATIONS AND REQUIREMENTS

The Emulator's Physical Characteristics

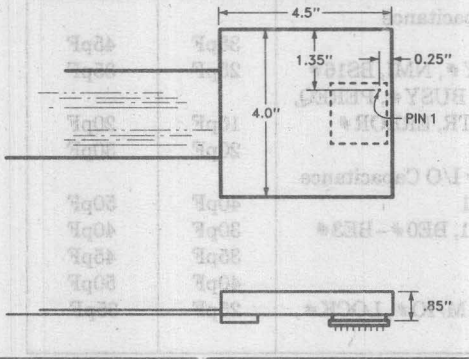
Unit	Width		Height		Length	
	inches	cm	inches	cm	inches	cm
Base Unit	13.4	34.0	4.6	11.7	11.0	27.9
Processor Module	3.8	9.7	0.7	1.8	4.4	11.2
Optional Isolation Board	3.8	9.7	0.5	1.3	4.4	11.2
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Cable	1.9	4.8			17.3	43.9
Target-Adapter Cable	2.3	5.3	0.5	1.3	5.8	14.7
Serial Cable					144	366
Optional Clips Pod	3.3	8.4	0.8	2.0	6.0	15.2

The Processor Module and Bus Isolation Board Dimensions



ICE™-386 DX 33 MHz SPECIFICATIONS AND REQUIREMENTS

The Processor Module and Bus Isolation Board Dimensions



ELECTRICAL SPECIFICATIONS

The synchronization input lines must be valid for at least four CLK2 cycles as they are only sampled on every other cycle. These input lines are standard TTL inputs. The synchronization output lines are driven by TTL open collector outputs that have 4.7K-ohm pull-up resistors. The synchronization input and output signals on the optional clips pod are standard TTL input and outputs.

AC Specifications With the Bus Isolation Board Installed

Symbol	Parameter	Minimum	Maximum	Notes
t1	CLK2 period	40 nS	t1 Max	
t2a	CLK2 high time	t2a Min + 2 nS		@ 2V
t3b	CLK2 low time	t3b Min + 2 nS		@ 0.8v
t6	A2-A31 valid delay	t6 Min + 3.5 nS	t6 Max + 24.6 nS	CL = 120 pF
t7	A2-A31 float delay	t14 Min + 5.5 nS	t14 Max + 32.6 nS	
t8	BE0# – BE3#, LOCK# valid delay	t8 Min + 3.5 nS	t8 Max + 24.6	CL = 75pF
t9	BE0# – BE3#, LOCK# float delay	t14 Min + 5.5 nS	t14 Max + 32.6	
t10	W/R#, M/IO#, D/C#, ADS# valid delay	t10 Min + 3.5 nS	t10 Min + 24.6	CL = 75 pF
t11	W/R#, M/IO#, D/C#, ADS# float delay	t14 Min + 5.5 nS	t14 Max + 32.6	
t12	D0-D31 write data valid delay	t12 Min + 4.5 nS	t12 Max + 20.6	CL = 120 pF
t13	D0-D31 write data float delay	7.5 nS	41.6 nS	
t14	HLDA valid delay	t14 Min = 3 nS	t14 Max + 21.2 nS	
t16	NA# hold time	t16 Min + 10.6 nS		
t18	BS16# hold time	t18 Min + 10.6 nS		
t20	READY# hold time	t20 Min + 10.6 nS		
t21	D0-D31 read setup time	t21 Min + 8.5 nS		
t22	D0-D31 read hold time	t22 Min + 7.6 nS		
t24	HOLD hold time	t24 Min + 10.6 nS		
t25	RESET setup time	t25 Min + 2.1 nS		
t26	RESET hold time	t26 Min + 2.1 nS		
t28	NMI, INTR hold time	t28 Min + 10.6 nS		
t30	PEREQ, ERROR#, BUSY# hold time	t30 Min + 10.6 nS		

SPECIFICATIONS

Emulator Capacitance Specifications

Symbol	Description	Typical	TAC Installed
C_{IN}	Input Capacitance		
	CLK2	35pF	45pF
	READY#, NMI, BS16#	25pF	35pF
	HOLD, BUSY#, PEREQ, NA#, INTR, ERROR#	10pF	20pF
	RESET	20pF	30pF
C_{OUT}	Output or I/O Capacitance		
	D0–D31	40pF	50pF
	A2–A31, BE0#–BE3#	30pF	40pF
	D/C#	35pF	45pF
	W/R#	40pF	50pF
	ADS#, M/IO#, LOCK#, HLDA	25pF	35pF

Note 1: Not tested. These specifications include the 80386 component and all additional emulator loading.
Note 2: The target-adapter cable adds a propagation delay of 0.5 nS.

Emulator DC Specifications Without the Bus Isolation Board Installed

Item	Description	Max.	Notes
PM-I_{CC}	Processor Module Supply Current	386-I_{CC}+ 1.5 A	
I_{IH}	Input High Leakage Current		
	A2–A31, BE0#–BE3#, D0–D31	20μA	1
	HLDA, NMI, BS16#	10μA	1
	ADS#, M/IO#, LOCK#, READY#	10μA	1
	W/R#, D/C#	30μA	1
	CLK2	15μA	1
	RESET	5μA	2
I_{IL}	Input Low Leakage Current		
	A2–A31, BE0#–BE3#, D0–D31	600μA	1
	HLDA, NMI, BS16#	10μA	1
	ADS#, M/IO#, LOCK#, READY#	10μA	1
	W/R#	110μA	1
	D/C#	610μA	1
	CLK2	15μA	1
	RESET	5μA	2

Note 1: This specification is the DC input loading of the emulator circuitry only and does not include any 80386 leakage current.
Note 2: This specification replaces the 80386 specification for this signal.

SPECIFICATIONS

Emulator DC Specifications
With the Bus Isolation Board Installed

Item	Description	Min.	Max.
BIB-I_{CC}	Bus Isolation Board Supply Current		PM-I_{CC} + 475 mA
V_{OL}	Output Low Voltage (I_{OL} = 48 mA)		
	A2–A31, BE0#–BE3#, D/C#, ADS#		0.5 v
	D0–D31, M/IO#, LOCK#, W/R#		0.5 v
	HLDA (I_{OL} = 24 mA)		0.44 v
V_{OH}	Output High Voltage (I_{OH} = 3 mA)		
	A2–A31, BE0#–BE3#, D/C#, ADS#	2.4 v	
	D0–D31, M/IO#, LOCK#, W/R#	2.4 v	
	HLDA (I_{OH} = 24 mA)	3.8 v	
I_{IH}	Input High Current		
	CLK2, RESET		1.0 μA
	READY#		25 μA
I_{IL}	Input Low Current		
	CLK2, RESET		1.0 μA
	READY#		250 μA
I_{IO}	Output Leakage Current		
	A2–A31, BE0#–BE3#, D/C#, ADS#		±20 μA
	D0–D31, M/IO#, LOCK#, W/R#		±20 μA

PROCESSOR MODULE INTERFACE CONSIDERATIONS

With the processor module directly attached to the target system without using the bus isolation board, the target system must meet the following requirements:

- The user bus controller must only drive the data bus during a valid read cycle of the emulator processor or while the emulator processor is in a hold state (the emulator processor uses the data bus to communicate with the emulator hardware).
- Before driving the address bus, the user system must gain control by asserting HOLD and receiving HLDA.
- The user reset signal is disabled during the interrogation mode. It is enabled in emulation, but is delayed by 2 or 4 CLK2 cycles.
- The user system must be able to drive one additional TTL load on all signals that go to the emulation processor.

When the target system does not satisfy the first two restrictions, the bus isolation board is used to isolate the emulation processor from the target system. With the isolation board installed, the processor CLK2 is restricted to running at 25 MHz.

The processor module derives its DC power from the target system through the 80386 socket. It requires 1500mA, including the 80386 current. The isolation board requires an additional 475mA.

The processor must be socketed. The printed circuit board design should locate the processor socket at the physical ends of the printed circuit board traces that connect the processor to the other logic of the target system. This reduces transmission line noise. Additionally, if the target system is enclosed in a box, pin one of the processor socket should be oriented to make connecting the processor module or target-adapter cable (TAC) easier.

The emulator uses the 386 microprocessor's pins C7, E13, and F13. The *80386 High Performance 32-Bit Microprocessor With Integrated Memory Management* data sheet specifies these pins as "N/C" (no connect). If the target system uses any of these pins, you must do one of the following:

- Use the bus isolation board.
- Use the target-adapter cable (TAC).
- Build an adapter to disconnect pins C7, E13, and F13 (i.e., a socket with these pins removed).

ICE™-386 DX 25 MHz SPECIFICATIONS AND REQUIREMENTS

HOST SYSTEM REQUIREMENTS

The user supplied host system can be either an IBM PC AT or Personal System/2 Model 60. Host system requirements to run the emulator include the following:

- DOS version 4.0, or Hewlett-Packard HP 9000 UNIX
- 640 Kbytes of RAM in conventional memory
- An Above board with 1 megabyte of RAM configured in expanded memory mode, EMM.SYS software version 3.2
- A 20 MB hard disk
- A serial port or the National Instruments GPIB-PCII, GPIB-PCIIA, or MC-GPIB board
- A math coprocessor if either the optional time tag board is used or if a math coprocessor resides on the target system

ELECTRICAL CHARACTERISTICS

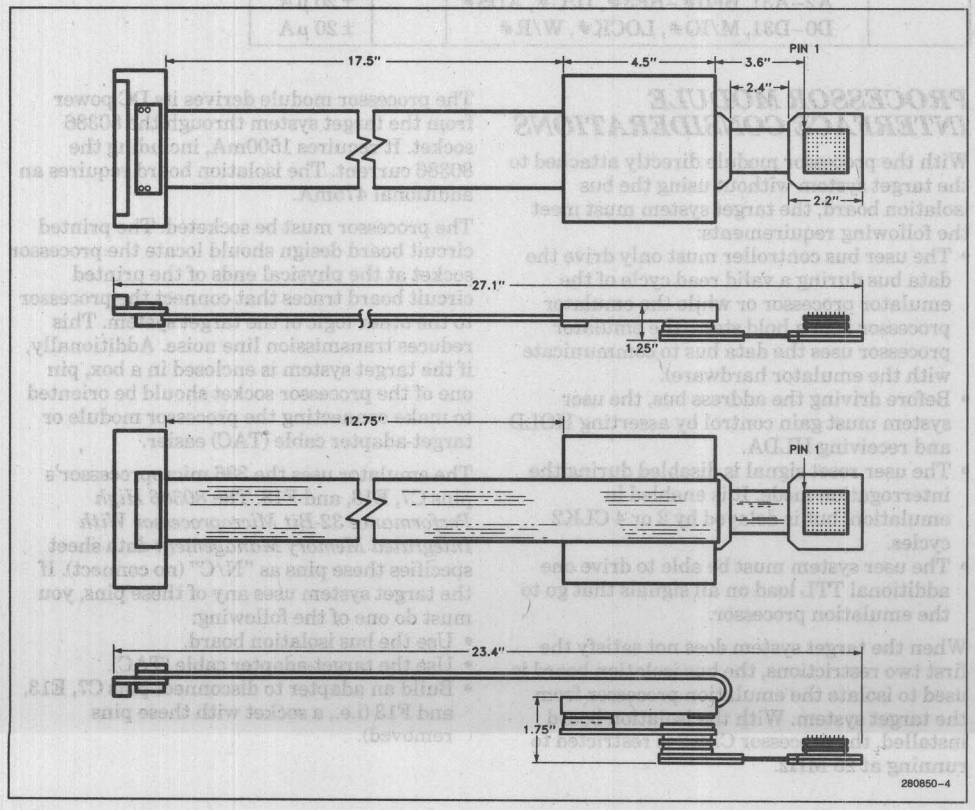
100–120V or 220–240V selectable
50–60 Hz
2 amps (AC max) @ 120V
1 amp (AC max) @ 240V

ENVIRONMENTAL CHARACTERISTICS

Operating temperature: +10° to +40° C (50° to 104° F)

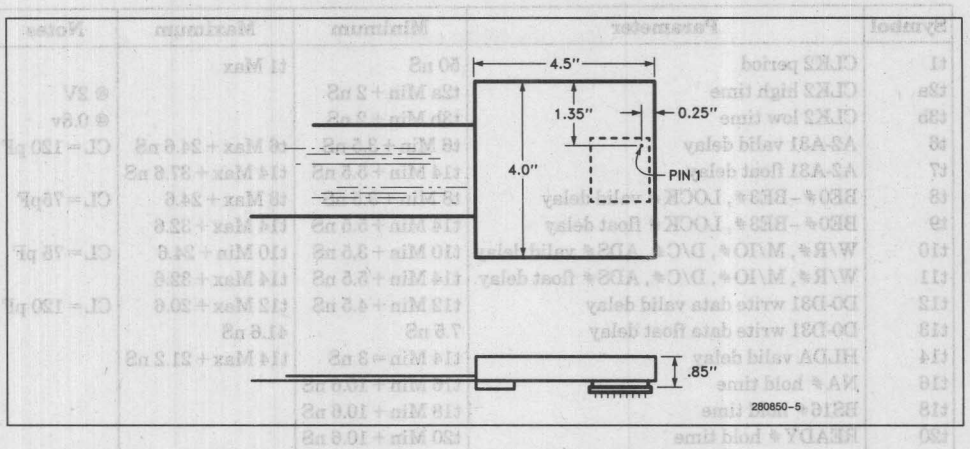
Operating Humidity: Maximum of 85% relative humidity, non-condensing

The Processor Module and Bus Isolation Board Dimensions



ICE™-386 DX 25 MHz SPECIFICATIONS AND REQUIREMENTS

The Processor Module and Bus Isolation Board Dimensions



The Emulator's Physical Characteristics

Unit	Width		Height		Length	
	inches	cm	inches	cm	inches	cm
Base Unit	13.4	34.0	4.6	11.7	11.0	27.9
Processor Module	3.8	9.7	0.7	1.8	4.4	11.2
Optional Isolation Board	3.8	9.7	0.5	1.3	4.4	11.2
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Cable	1.9	4.8			17.3	43.9
Target-Adapter Cable	2.3	5.3	0.5	1.3	5.8	14.7
Serial Cable					144	366
Optional Clips Pod	3.3	8.4	0.8	2.0	6.0	15.2

ELECTRICAL SPECIFICATIONS

The synchronization input lines must be valid for at least four CLK2 cycles as they are only sampled on every other cycle. These input lines are standard TTL inputs. The synchronization output lines are driven by TTL open collector outputs that have 4.7K-ohm pull-up resistors. The synchronization input and output signals on the optional clips pod are standard TTL input and outputs.

ICE™-386 DX 25 MHz SPECIFICATIONS AND REQUIREMENTS

AC Specifications With the Bus Isolation Board Installed

Symbol	Parameter	Minimum	Maximum	Notes
t1	CLK2 period	50 nS	t1 Max	
t2a	CLK2 high time	t2a Min + 2 nS		@ 2V
t3b	CLK2 low time	t3b Min + 2 nS		@ 0.8v
t6	A2-A31 valid delay	t6 Min + 3.5 nS	t6 Max + 24.6 nS	CL = 120 pF
t7	A2-A31 float delay	t14 Min + 5.5 nS	t14 Max + 37.6 nS	
t8	BE0# – BE3#, LOCK# valid delay	t8 Min + 3.5 nS	t8 Max + 24.6	CL = 75pF
t9	BE0# – BE3#, LOCK# float delay	t14 Min + 5.5 nS	t14 Max + 32.6	
t10	W/R#, M/IO#, D/C#, ADS# valid delay	t10 Min + 3.5 nS	t10 Min + 24.6	CL = 75 pF
t11	W/R#, M/IO#, D/C#, ADS# float delay	t14 Min + 5.5 nS	t14 Max + 32.6	
t12	D0-D31 write data valid delay	t12 Min + 4.5 nS	t12 Max + 20.6	CL = 120 pF
t13	D0-D31 write data float delay	7.5 nS	41.6 nS	
t14	HLDA valid delay	t14 Min = 3 nS	t14 Max + 21.2 nS	
t16	NA# hold time	t16 Min + 10.6 nS		
t18	BS16# hold time	t18 Min + 10.6 nS		
t20	READY# hold time	t20 Min + 10.6 nS		
t21	D0-D31 read setup time	t21 Min + 8.5 nS		
t22	D0-D31 read hold time	t22 Min + 7.6 nS		
t24	HOLD hold time	t24 Min + 10.6 nS		
t25	RESET setup time	t25 Min + 2.1 nS		
t26	RESET hold time	t26 Min + 2.1 nS		
t28	NMI, INTR hold time	t28 Min + 10.6 nS		
t30	PEREQ, ERROR#, BUSY# hold time	t30 Min + 10.6 nS		

SPECIFICATIONS

Emulator Capacitance Specifications

Symbol	Description	Typical	TAC Installed
C_{IN}	Input Capacitance		
	CLK2	35pF	45pF
	READY#, NMI, BS16#	25pF	35pF
	HOLD, BUSY#, PEREQ, NA#, INTR, ERROR#	10pF	20pF
	RESET	20pF	30pF
C_{OUT}	Output or I/O Capacitance		
	D0–D31	40pF	50pF
	A2–A31, BE0# – BE3#	30pF	40pF
	D/C#	35pF	45pF
	W/R#	40pF	50pF
	ADS#, M/IO#, LOCK#, HLDA	25pF	35pF

Note 1: Not tested. These specifications include the 80386 component and all additional emulator loading.
Note 2: The target-adapter cable adds a propagation delay of 0.5 nS.

SPECIFICATIONS

Emulator DC Specifications
Without the Bus Isolation Board Installed

Item	Description	Max.	Notes
PM-I_{CC}	Processor Module Supply Current	386SX-I_{CC}+ 1.5 A	
I_{IH}	Input High Leakage Current		
	A2–A31, BE0#–BE3#, D0–D31	20μA	1
	HLDA, NMI, BS16#	10μA	1
	ADS#, M/IO#, LOCK#, READY#	10μA	1
	W/R#, D/C#	30μA	1
	CLK2	15μA	1
	RESET	5μA	2
I_{IL}	Input Low Leakage Current		
	A2–A31, BE0#–BE3#, D0–D31	600μA	1
	HLDA, NMI, BS16#	10μA	1
	ADS#, M/IO#, LOCK#, READY#	10μA	1
	W/R#110	μA	1
	D/C#	610μA	1
	CLK2	15μA	1
	RESET	5μA	2

Note 1: This specification is the DC input loading of the emulator circuitry only and does not include any 80386 leakage current.
Note 2: This specification replaces the 80386 specification for this signal.

Emulator DC Specifications
With the Bus Isolation Board Installed

Item	Description	Min.	Max.
BIB-I_{CC}	Bus Isolation Board Supply Current		PM-I_{CC}+ 475 mA
V_{OL}	Output Low Voltage (I_{OL}=48 mA)		
	A2–A31, BE0#–BE3#, D/C#, ADS#		0.5 v
	D0–D31, M/IO#, LOCK#, W/R#		0.5 v
	HLDA (I_{OL}=24 mA)		0.44 v
V_{OH}	Output High Voltage (I_{OH}=3 mA)		
	A2–A31, BE0#–BE3#, D/C#, ADS#	2.4 v	
	D0–D31, M/IO#, LOCK#, W/R#	2.4 v	
	HLDA (I_{OH}=24 mA)	3.8 v	
I_{IH}	Input High Current		
	CLK2, RESET		1.0 μA
	READY#		25 μA
I_{IL}	Input Low Current		
	CLK2, RESET		1.0 μA
	READY#		250 μA
I_{IO}	Output Leakage Current		
	A2–A31, BE0#–BE3#, D/C#, ADS#		±20 μA
	D0–D31, M/IO#, LOCK#, W/R# ±20 μA		

ICE™-386 SX 20 MHz SPECIFICATIONS AND REQUIREMENTS

PROCESSOR MODULE INTERFACE CONSIDERATIONS

With the processor module directly attached to the target system without using the bus isolation board, the target system must meet the following requirements:

- The user bus controller must only drive the data bus during a valid read cycle of the emulator processor or while the emulator processor is in a hold state (the emulator processor uses the data bus to communicate with the emulator hardware).
- Before driving the address bus, the user system must gain control by asserting HOLD and receiving HLDA.
- The user reset signal is disabled during the interrogation mode. It is enabled in emulation, but is delayed by 2 or 4 CLK2 cycles.
- The user system must be able to drive one additional TTL load on all signals that go to the emulation processor.

When the target system does not satisfy the first two restrictions, the bus isolation board is used to isolate the emulation processor from the target system. With the isolation board installed, the processor CLK2 is restricted to running at 25 MHz.

The processor module derives its DC power from the target system through the 80386 socket. It requires 1500mA, including the 80386 current. The isolation board requires an additional 475mA.

The processor must be socketed. The printed circuit board design should locate the processor socket at the physical ends of the printed circuit board traces that connect the processor to the other logic of the target system. This reduces transmission line noise. Additionally, if the target system is enclosed in a box, pin one of the processor socket should be oriented to make connecting the processor module or target-adapter cable (TAC) easier.

The emulator uses the 386 microprocessor's pins C7, E13, and F13. The *80386 High Performance 32-Bit Microprocessor With Integrated Memory Management* data sheet specifies these pins as "N/C" (no connect). If the target system uses any of these pins, you must do one of the following:

- Use the bus isolation board.
- Use the target-adapter cable (TAC).
- Build an adapter to disconnect pins C7, E13, and F13 (i.e., a socket with these pins removed).

HOST SYSTEM REQUIREMENTS

The user supplied host system can be either an IBM PC AT or Personal System/2 Model 60. Host system requirements to run the emulator include the following:

- DOS version 4.0, or Hewlett-Packard HP9000 UNIX
- 640 Kbytes of RAM in conventional memory
- An Above board with 1 megabyte of RAM configured in expanded memory mode, EMM.SYS software version 3.2
- A 20 MB hard disk
- A serial port or the National Instruments GPIB-PCII, GPIB-PCIIA, or MC-GPIB board
- A math coprocessor if either the optional time tag board is used or if a math coprocessor resides on the target system

ELECTRICAL CHARACTERISTICS

100–120V or 220–240V selectable
50–60 Hz
2 amps (AC max) @ 120V
1 amp (AC max) @ 240V

ENVIRONMENTAL CHARACTERISTICS

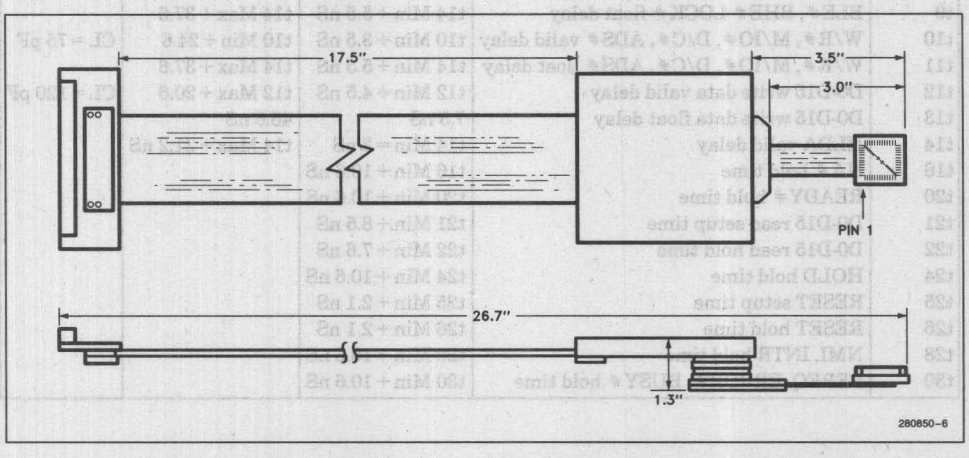
Operating temperature:	+10°C to +40°C (50°F to 104°F)
Operating Humidity:	Maximum of 85% relative humidity, non-condensing

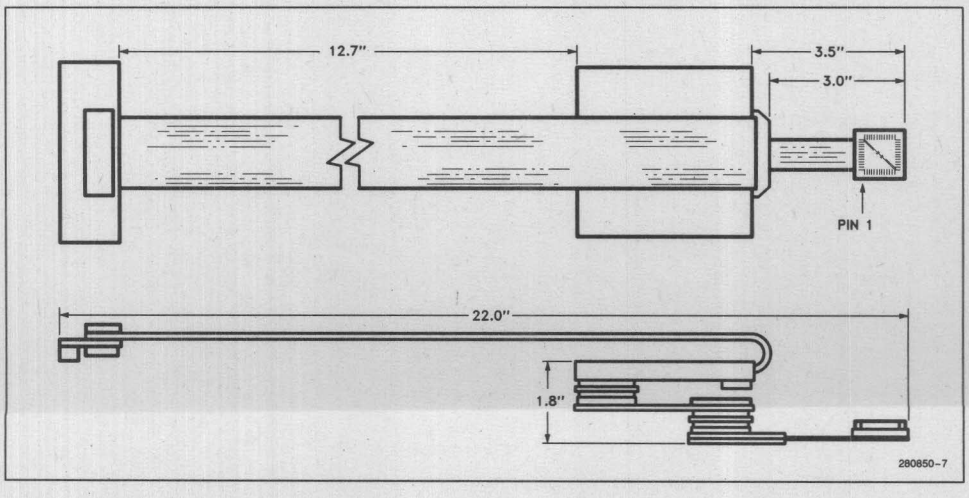
ICE™-386 SX 20 MHz SPECIFICATIONS AND REQUIREMENTS

The Emulator's Physical Characteristics

Unit	Width		Height		Length	
	inches	cm	inches	cm	inches	cm
Base Unit	13.4	34.0	4.6	11.7	11.0	27.9
Processor Module	3.8	9.7	0.7	1.8	4.4	11.2
Optional Isolation Board	3.8	9.7	0.5	1.3	4.4	11.2
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Cable	1.9	4.8			17.3	43.9
Target-Adapter Cable	2.3	5.3	0.5	1.3	5.1	13.0
Serial Cable					144	366
Optional Clips Pod	3.3	8.4	0.8	2.0	6.0	15.2

The Processor Module and Bus Isolation Board Dimensions





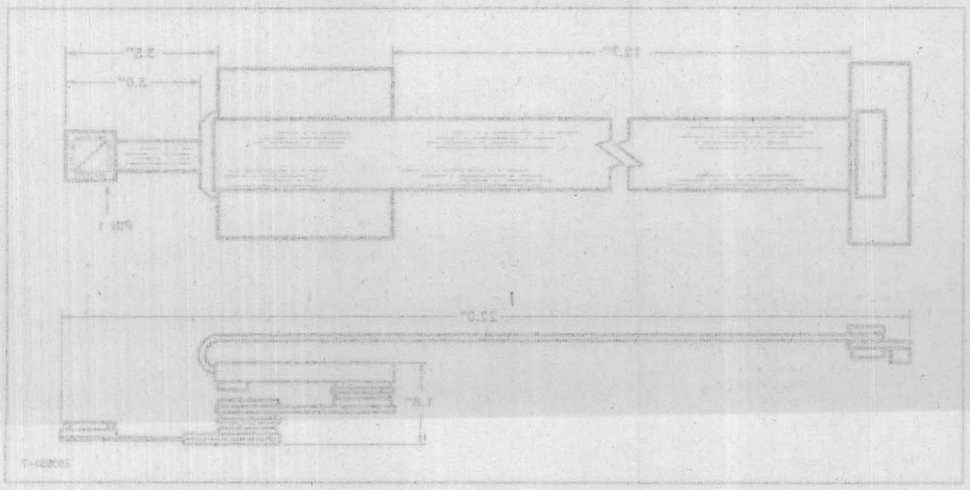
ICE™-386 SX 20 MHz SPECIFICATIONS AND REQUIREMENTS

ELECTRICAL SPECIFICATIONS

The synchronization input lines must be valid for at least four CLK2 cycles as they are only sampled on every other cycle. These input lines are standard TTL inputs. The synchronization output lines are driven by TTL open collector outputs that have 4.7K-ohm pull-up resistors. The synchronization input and output signals on the optional clips pod are standard TTL input and outputs.

AC Specifications With the Bus Isolation Board Installed

Symbol	Parameter	Minimum	Maximum	Notes
t1	CLK2 period	50 nS	t1 Max	
t2a	CLK2 high time	t2a Min + 2 nS		@ 2V
t3b	CLK2 low time	t3b Min + 2 nS		@ 0.8v
t6	A1-A23 valid delay	t6 Min + 3.5 nS	t6 Max + 24.6 nS	CL = 120 pF
t7	A1-A23 float delay	t14 Min + 5.5 nS	t14 Max + 37.6 nS	
t8	BLE#, BHE# LOCK# valid delay	t8 Min + 3.5 nS	t8 Max + 24.6	CL = 75pF
t9	BLE#, BHE# LOCK# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t10	W/R#, M/IO#, D/C#, ADS# valid delay	t10 Min + 3.5 nS	t10 Min + 24.6	CL = 75 pF
t11	W/R#, M/IO#, D/C#, ADS# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t12	D0-D15 write data valid delay	t12 Min + 4.5 nS	t12 Max + 20.6	CL = 120 pF
t13	D0-D15 write data float delay	7.5 nS	45.6 nS	
t14	HLDA valid delay	t14 Min = 3 nS	t14 Max + 21.2 nS	
t16	NA# hold time	t16 Min + 10.6 nS		
t20	READY# hold time	t20 Min + 10.6 nS		
t21	D0-D15 read setup time	t21 Min + 8.5 nS		
t22	D0-D15 read hold time	t22 Min + 7.6 nS		
t24	HOLD hold time	t24 Min + 10.6 nS		
t25	RESET setup time	t25 Min + 2.1 nS		
t26	RESET hold time	t26 Min + 2.1 nS		
t28	NMI, INTR hold time	t28 Min + 10.6 nS		
t30	PEREQ, ERROR#, BUSY# hold time	t30 Min + 10.6 nS		



SPECIFICATIONS

Emulator Capacitance Specifications With the Target-Adapter Cable Installed

Symbol	Description	Typical (Note 1)
C_{IN}	Input Capacitance	
	CLK2	55pF
	READY#, ERROR#	35pF
	HOLD, BUSY#, PEREQ, NA#, INTR, NMI	20pF
	RESET	30pF
C_{OUT}	Output or I/O Capacitance	
	D15-D0	50pF
	A15-A1, BLE#	40pF
	A23-A16, BHE#, D/C#	30pF
	HLDA, W/R#	55pF
	ADS#, M/IO#, LOCK#	35pF

Note 1: Not tested. These specifications include the 80386SX component and all additional emulator loading.

Emulator DC Specifications Without the Bus Isolation Board Installed

Item	Description	Max.	Notes
PM-I_{CC}	Processor Module Supply Current	386SX-I_{CC} + 940 mA	
I_{IH}	Input High Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, HLDA	0.02 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.03 mA	1
	CLK2	0.04 mA	1
	RESET	0.06 mA	2
I_{IL}	Input Low Leakage Current		
	A23-A1, BLE#, BHE#, D/C#	0.6 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.51 mA	1
	CLK2	0.62 mA	1
	RESET	0.6 mA	2
	HLDA	0.02 mA	1

Note 1: This specification is the DC input loading of the emulator circuitry only and does not include any 80386SX leakage current.
Note 2: This specification replaces the 80386SX specification for this signal.

SPECIFICATIONS

Emulator DC Specifications
With the Bus Isolation Board Installed

Item	Description	Min.	Max.
BIB-I_{CC}	Bus Isolation Board Supply Current		PM-I_{CC} + 350 mA
V_{OL}	Output Low Voltage (I_{OL} = 48 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#		0.5v
	D15-D0, M/IO#, LOCK#, W/R#		0.5v
	HLDA (I_{OL} = 24 mA)		0.44 v
V_{OH}	Output High Voltage (I_{OH} = 3 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#	2.4 v	
	D15-D0, M/IO#, LOCK#, W/R#	2.4v	
	HLDA (I_{OH} = 24 mA)	3.8 v	
I_{IH}	Input High Current		
	CLK2, RESET		1.0 μA
	READY#		2.5 μA
I_{IL}	Input Low Current		
	CLK2, RESET		1.0 μA
	READY#		250 μA
I_{IO}	Output Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, ADS#		±20 μA
	D15-D0, M/IO#, LOCK#, W/R#		±20 mA

PROCESSOR MODULE INTERFACE CONSIDERATIONS

With the processor module directly attached to the target system without using the bus isolation board, the target system must meet the following requirements:

- The user bus controller must only drive the data bus during a valid read cycle of the emulator processor or while the emulator processor is in a hold state (the emulator processor uses the data bus to communicate with the emulator hardware).
- Before driving the address bus, the user system must gain control by asserting HOLD and receiving HLDA.
- The user reset signal is disabled during the interrogation mode. It is enabled in emulation, but is delayed by 2 or 4 CLK2 cycles.
- The user system must be able to drive one additional TTL load on all signals that go to the emulation processor.

When the target system does not satisfy the first two restrictions, the bus isolation board is used to isolate the emulation processor from the target system. With the isolation board installed, the processor CLK2 is restricted to running at 20 MHz.

The processor module derives its DC power from the target system through the 80386SX socket. It requires 1400mA, including the 80386SX current. The isolation board requires an additional 350mA.

The processor must be socketed, for example using Textool 2-0100-07243-000 or AMP 821949-4 sockets.

The printed circuit board design should locate the processor socket at the physical ends of the printed circuit board traces that connect the processor to the other logic of the target system. This reduces transmission line noise. Additionally, if the target system is enclosed in a box, pin one of the processor socket should be oriented away from the target system's box opening to make connecting the target-adapter cable easier.

ICE™-376 SPECIFICATIONS AND REQUIREMENTS

HOST SYSTEM REQUIREMENTS

The user supplied host system can be either an IBM PC AT or Personal System/2 Model 60. Host system requirements to run the emulator include the following:

- DOS version 4.0, or Hewlett-Packard HP9000 UNIX
- 640 Kbytes of RAM in conventional memory
- An Above board with 1 megabyte of RAM configured in expanded memory mode, EMM.SYS software version 3.2
- A 20 MB hard disk
- A serial port or the National Instruments GPIB-PCII, GPIB-PCIIA, or MC-GPIB board
- A math coprocessor if either the optional time tag board is used or if a math coprocessor resides on the target system

ELECTRICAL CHARACTERISTICS

100–120V or 220–240V selectable
50–60 Hz
2 amps (AC max) @ 120V
1 amp (AC max) @ 240V

ENVIRONMENTAL CHARACTERISTICS

Operating temperature: +10°C to +40°C (50°F to 104°F)

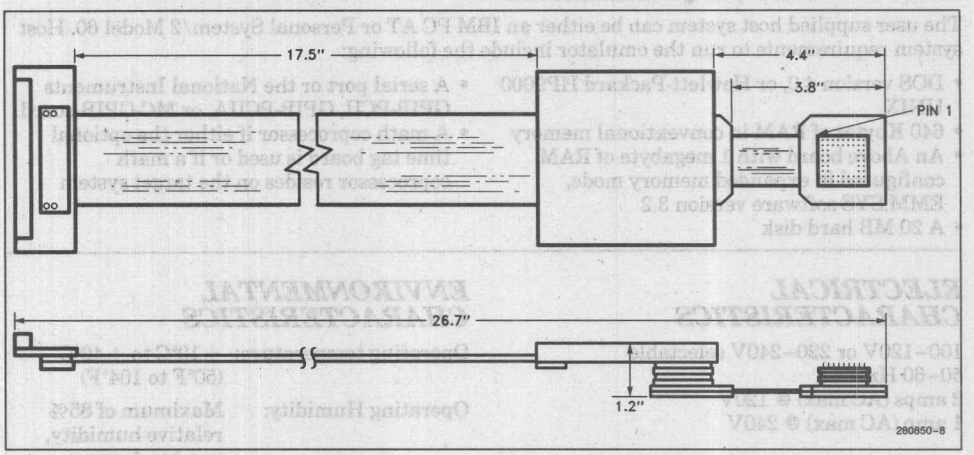
Operating Humidity: Maximum of 85% relative humidity, non-condensing

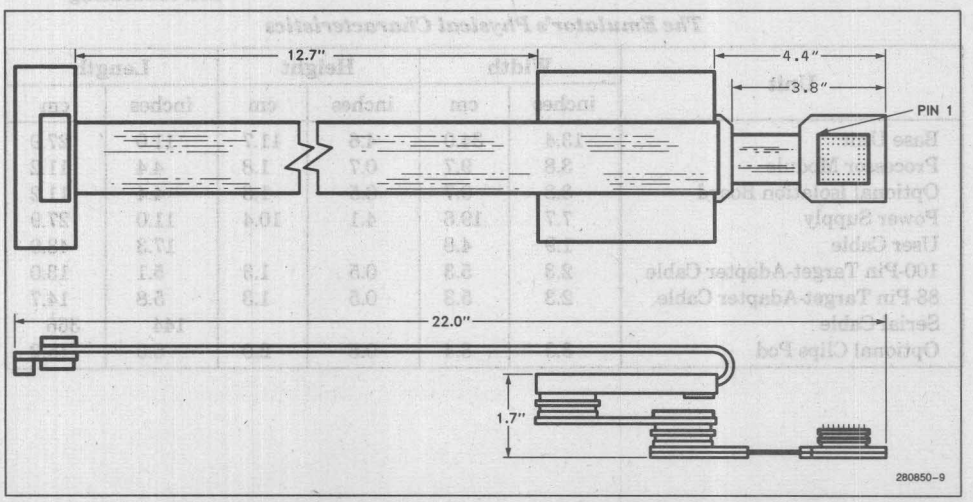
The Emulator's Physical Characteristics

Unit	Width		Height		Length	
	inches	cm	inches	cm	inches	cm
Base Unit	13.4	34.0	4.6	11.7	11.0	27.9
Processor Module	3.8	9.7	0.7	1.8	4.4	11.2
Optional Isolation Board	3.8	9.7	0.5	1.3	4.4	11.2
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Cable	1.9	4.8			17.3	43.9
100-Pin Target-Adapter Cable	2.3	5.3	0.5	1.3	5.1	13.0
88-Pin Target-Adapter Cable	2.3	5.3	0.5	1.3	5.8	14.7
Serial Cable					144	366
Optional Clips Pod	3.3	8.4	0.8	2.0	6.0	15.2

ICE™-376 SPECIFICATIONS AND REQUIREMENTS

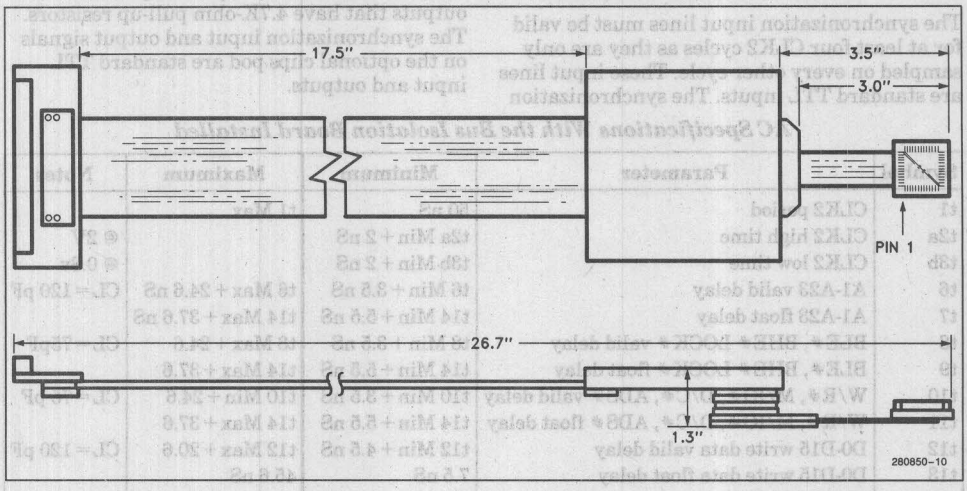
The Processor Module and Bus Isolation Board Dimensions (88 Pin PGA)

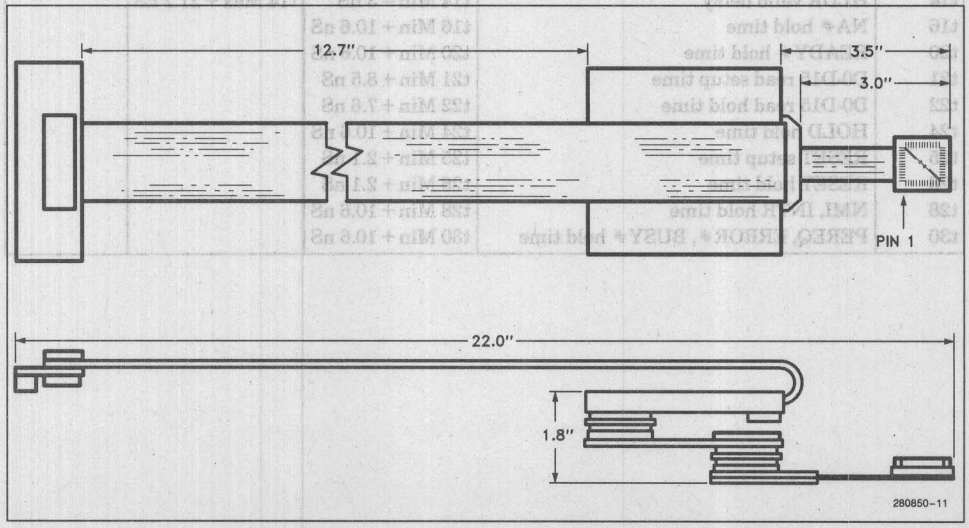




ICE™-376 SPECIFICATIONS AND REQUIREMENTS

The Processor Module and Bus Isolation Board Dimensions (100 Pin PQFP)





ICE™-376 SPECIFICATIONS AND REQUIREMENTS

ELECTRICAL SPECIFICATIONS

The synchronization input lines must be valid for at least four CLK2 cycles as they are only sampled on every other cycle. These input lines are standard TTL inputs. The synchronization output lines are driven by TTL open collector outputs that have 4.7K-ohm pull-up resistors. The synchronization input and output signals on the optional clips pod are standard TTL input and outputs.

AC Specifications With the Bus Isolation Board Installed

Symbol	Parameter	Minimum	Maximum	Notes
t1	CLK2 period	50 nS	t1 Max	
t2a	CLK2 high time	t2a Min + 2 nS		@ 2V
t3b	CLK2 low time	t3b Min + 2 nS		@ 0.8v
t6	A1-A23 valid delay	t6 Min + 3.5 nS	t6 Max + 24.6 nS	CL = 120 pF
t7	A1-A23 float delay	t14 Min + 5.5 nS	t14 Max + 37.6 nS	
t8	BLE#, BHE# LOCK# valid delay	t8 Min + 3.5 nS	t8 Max + 24.6	CL = 75pF
t9	BLE#, BHE# LOCK# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t10	W/R#, M/IO#, D/C#, ADS# valid delay	t10 Min + 3.5 nS	t10 Min + 24.6	CL = 75 pF
t11	W/R#, M/IO#, D/C#, ADS# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t12	D0-D15 write data valid delay	t12 Min + 4.5 nS	t12 Max + 20.6	CL = 120 pF
t13	D0-D15 write data float delay	7.5 nS	45.6 nS	
t14	HLDA valid delay	t14 Min = 3 nS	t14 Max + 21.2 nS	
t16	NA# hold time	t16 Min + 10.6 nS		
t20	READY# hold time	t20 Min + 10.6 nS		
t21	D0-D15 read setup time	t21 Min + 8.5 nS		
t22	D0-D15 read hold time	t22 Min + 7.6 nS		
t24	HOLD hold time	t24 Min + 10.6 nS		
t25	RESET setup time	t25 Min + 2.1 nS		
t26	RESET hold time	t26 Min + 2.1 nS		
t28	NMI, INTR hold time	t28 Min + 10.6 nS		
t30	PEREQ, ERROR#, BUSY# hold time	t30 Min + 10.6 nS		

SPECIFICATIONS

Emulator Capacitance Specifications With Target-Adapter Cable Installed

Symbol	Description	Typical (Note 1)
C_{IN}	Input Capacitance	
	CLK2	55pF
	READY#, ERROR#	35pF
	HOLD, BUSY#, PEREQ, NA#, INTR, NMI	20pF
	RESET	30pF
C_{OUT}	Output or I/O Capacitance	
	D15-D0	50pF
	A15-A1, BLE#	40pF
	A23-A16, BHE#, D/C#	30pF
	HLDA, W/R#	55pF
	ADS#, M/IO#, LOCK#	35pF

Note 1: Not tested. These specifications include the 80376 component and all additional emulator loading.

Emulator DC Specifications Without the Bus Isolation Board Installed

Item	Description	Max.	Notes
PM-I_{CC}	Processor Module Supply Current	376-I_{CC} + 940 mA	
I_{IH}	Input High Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, HLDA	0.02 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.03 mA	1
	CLK2	0.04 mA	1
	RESET	0.06 mA	2
I_{IL}	Input Low Leakage Current		
	A23-A1, BLE#, BHE#, D/C#	0.6 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.51 mA	1
	CLK2	0.62 mA	1
	RESET	0.6 mA	2
	HLDA	0.02 mA	1

Note 1: This specification is the DC input loading of the emulator circuitry only and does not include any 80376 leakage current.
Note 2: This specification replaces the 80376 specification for this signal.

SPECIFICATIONS

Emulator DC Specifications
With the Bus Isolation Board Installed

Item	Description	Min.	Max.
BIB-I_{CC}	Bus Isolation Board Supply Current		PM-I_{CC} + 350 mA
V_{OL}	Output Low Voltage (I_{OL} = 48 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#		0.5v
	D15-D0, M/IO#, LOCK#, W/R#		0.5v
	HLDA (I_{OL} = 24 mA)		0.44 v
V_{OH}	Output High Voltage (I_{OH} = 3 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#	2.4 v	
	D15-D0, M/IO#, LOCK#, W/R#	2.4 v	
	HLDA (I_{OH} = 24 mA)	3.8 v	
I_{IH}	Input High Current		
	CLK2, RESET		1.0 μA
	READY#		25 μA
I_{IL}	Input Low Current		
	CLK2, RESET		1.0 μA
	READY#		250 μA
I_{IO}	Output Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, ADS#		±20 μA
	D15-D0, M/IO#, LOCK#, W/R#		±20 μA

PROCESSOR MODULE INTERFACE CONSIDERATIONS

With the processor module directly attached to the target system without using the bus isolation board, the target system must meet the following requirements:

- The user bus controller must only drive the data bus during a valid read cycle of the emulator processor or while the emulator processor is in a hold state (the emulator processor uses the data bus to communicate with the emulator hardware).
- Before driving the address bus, the user system must gain control by asserting HOLD and receiving HLDA.
- The user reset signal is disabled during the interrogation mode. It is enabled in emulation, but is delayed by 2 or 4 CLK2 cycles.
- The user system must be able to drive one additional TTL load on all signals that go to the emulation processor.

When the target system does not satisfy the first two restrictions, the bus isolation board is used to isolate the emulation processor from the target system. With the isolation board installed, the processor CLK2 is restricted to running at 20 MHz.

The processor module derives its DC power from the target system through the 80376 socket. It requires 1400mA, including the 80376 current. The isolation board requires an additional 350mA.

The processor must be socketed, for example using Textool 2-0100-07243-000 or AMP 821949-4 sockets.

The printed circuit board design should locate the processor socket at the physical ends of the printed circuit board traces that connect the processor to the other logic of the target system. This reduces transmission line noise. Additionally, if the target system is enclosed in a box, pin one of the processor socket should be oriented away from the target system's box opening to make connecting the target-adapter cable easier.

ORDERING INFORMATION

IN-CIRCUIT EMULATORS ORDER CODES

pICE376D	ICE376 In-circuit Emulator for 80376 component. Operates to 16 MHz. Includes control unit, power supply, 376 Processor Module with PQFP adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
ICE37616H	HP9000 hosted In-circuit Emulator for 80376 component. Operates to 16 MHz.
ICE386SX20D	ICE386SX 20 MHz In-circuit Emulator for 80386 SX component. Includes control unit, power supply, 386 SX Processor Module with PQFP adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
ICE386SX20H	HP9000 hosted In-circuit Emulator for 80386 SX component. Operates to 20 MHz.
pICE38625D	ICE386 25 MHz In-circuit Emulator for 80386 DX component. Includes control unit, power supply, 386 DX Processor Module with 132 pin PGA adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
ICE386DX33D	ICE386DX 33 MHz In-circuit Emulator for 80386 DX component. Includes control unit, power supply, 386 DX Processor Module with 132 pin PGA adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
ICE386DX25H	HP9000 hosted In-circuit Emulator for 80386 DX component. Operates to 25 MHz.
ICE386DX33H	HP9000 hosted In-circuit Emulator for the 386 DX component. This custom unit operates to 33 MHz.

ORDERING INFORMATION

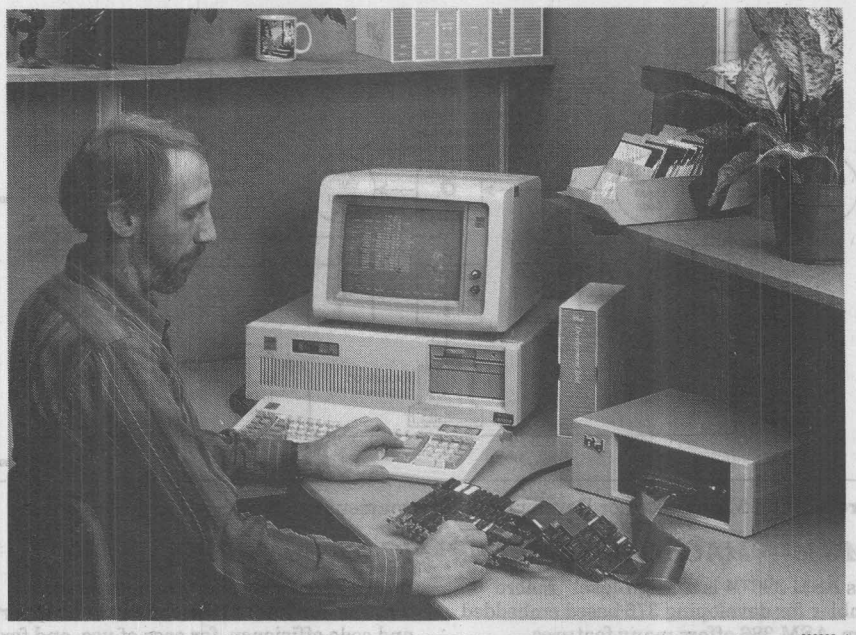
IN-CIRCUIT EMULATOR CONVERSION KITS ORDER CODES

pTOICE386SX20D	Conversion kit to adapt emulator base to support the 80386 SX component. Operates to 20 MHz. Includes ICE386SX 20 MHz Processor Module and DOS 3.x host software.
pICE376TO386D	Conversion kit to adapt ICE376 emulator to support the 80386 DX component at 25 MHz. Includes ICE386 25 MHz Processor Module and DOS 3.x host software.
pICE386SXTO376D	Conversion kit to adapt ICE386SX 16 or 20 MHz emulator to support the 80376 component. Operates to 16 MHz. Includes ICE376 emulator Processor Module and DOS 3.x host software.
pICE386SXTO386D	Conversion kit to adapt ICE386SX 16 or 20 MHz emulator to support the 80386 DX component at 25 MHz. Includes ICE386 25 MHz Processor Module and DOS 3.x host software.
pICE386TO376D	Conversion kit to adapt ICE386 25 MHz emulator to support the 80376 component. Operates to 16 MHz. Includes ICE376 emulator Processor Module and DOS 3.x host software.
TOICE386DX33D	Conversion kit to adapt emulator base to support the 80386 DX 33 MHz component. Operates to 33 MHz. Includes ICE386DX 33 MHz emulator Processor Module and DOS 3.x host software.

IN-CIRCUIT EMULATOR OPTION ORDER CODES

p88PGAADAPT	Adaptor for ICE376 emulator to support 88 pin PGA component packaging.
pICE3XXCPO	Clips Pod Option for ICE376, ICE386SX 16 or 20 MHz, ICE386 25 MHz, and ICE386DX 33 MHz emulators.
pICE3XXTTB	Time Tag Board Option for ICE376, ICE386SX 16 or 20 MHz, ICE386 25 MHz, and ICE386DX 33 MHz emulators.
DT0AB	2 MB Above Board.

INTEL 376™ FAMILY DEVELOPMENT SUPPORT



280903-1

COMPREHENSIVE DEVELOPMENT SUPPORT FOR THE INTEL 376™ EMBEDDED PROCESSORS

The perfect complement to the Intel 376™ embedded processor is the optimum development solution. From a single source, Intel, comes a complete, synergistic hardware and software development toolset, delivering full access to the power of the Intel 376 architecture.

Intel development tools are easy to use, yet powerful, with ease-of-use user interface techniques and productivity boosting features such as symbolic debugging. And you'll find Intel first to market with the tools needed to start development, and with lasting product quality and comprehensive support to keep development on-track.

If what interests you is getting the best product to market in as little time as possible, Intel is the choice.

FEATURES

- Full speed emulation up to 20 MHz
- Source line display and symbolics allow debugging in the context of the original program
- Intel high-level languages provide architectural extensions for manipulating hardware directly without assembly language routines
- A common object code format (Intel OMF386) supports symbolic debug and permits the intermixing of modules written in various languages—Intel's assembler, C, PL/M, and FORTRAN
- A common OMF386 permits compilers and assembler to seamlessly operate with in-circuit and software debug tools
- ROM-able code is output directly from the language tools, significantly reducing the effort necessary to integrate software into the final target system
- Extensive support for the Intel 80387SX math coprocessor
- Operation in DOS IBM PC AT*, PS/2 Model 60 and 80, or compatible) and VAX/VMS* hosted environments

November 1990
Order Number: 280903-001

INTEL 376™ FAMILY DEVELOPMENT SUPPORT

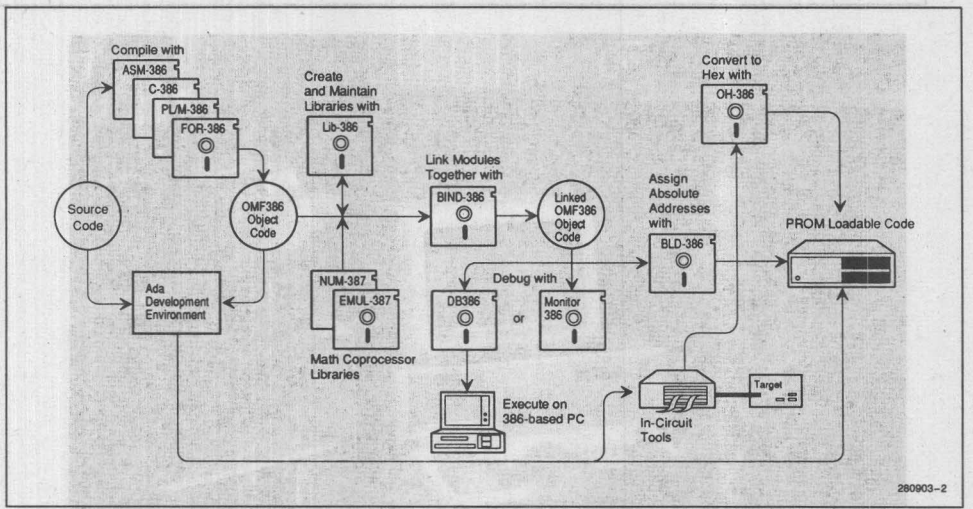


Figure 1: Intel Microprocessor Development Environment

ASM 386™ MACRO ASSEMBLER

Intel's ASM 386™ is a "high-level" macro assembler for developing 376 based embedded system. ASM 386 offers many features normally found only in high-level languages. The macro facility in ASM 386 saves development time by allowing common program sequences to be coded only once. The assembly language is strongly typed, performing extensive checks on the usage of variables and labels.

Other Intel ASM 386 features include:

- "High-level" assembler mnemonics to simplify the language
- Structures and records for data representation
- Support for Intel's standard object code format for source-level symbolic debug, and for linking object modules from other Intel386/376 languages
- Full support for processor and math coprocessor instruction sets
- 16 bit or 32 bit address overrides
- Supports development for Virtual 86, Real, 286 Protected, and 386 Protected modes

iC-386 COMPILER

Intel's iC-386 compiler provides special features for Intel 376 architectural support and code efficiency, for ease of use, and for compatibility with other Intel development tools.

The iC-386 compiler produces code for Intel 376 processor from C source files, and conforms to the ANSI standard (ANS X3.159-1989) for the C programming language.

Key Intel iC-386 features include:

- Controls to tailor the compilation for each step of your application development process
- In-line versions of many ANSI-standard library functions
- Uses expanded memory (LIM Version 3.0 and higher)
- Object code (including supplied run-time libraries) suitable for ROM
- Three different levels of optimization
- A choice of three segmentation memory models (small, compact, and flat) to create compact and efficient code
- In-line processor-specific functions and time-saving macros that provide access to the special features of the Intel 376 embedded processor

INTEL 376™ FAMILY DEVELOPMENT SUPPORT

- In-line floating-point instructions for the 387™ SX™ numerics coprocessor
- Time-saving macros and functions to help assembly language routines interface with Intel's high-level programming languages
- The standard C run-time library plus libraries for floating-point support
- An easy interface to Intel's non-C programming languages, along with object module compatibility between Intel C and non-C compilers
- Support for source-level debugging using the Intel DB-386 Software Debugger
- Programming with subsystems, allowing mixed segmentation memory models
- Extensions to the ANSI C standard for compatibility with previous versions of Intel C

The iC-386 libraries contain over 200 functions. The libraries and header files make development of iC-386 applications easier by providing:

- Fast and efficient functions for common programming tasks
- Interfaces to standard and custom execution environments
- Built-in versions of some functions

PL/M-386 COMPILER

Intel's PL/M-386 is a structured high-level system implementation language for the Intel 376 embedded processor. PL/M-386 supports the implementation of protected operating system software by providing built-in procedures and variables to access the Intel 376 architecture.

For efficient code generation, PL/M-386 features four levels of optimization, a virtual symbol table, and four models of program size and memory usage.

Other Intel PL/M-386 features include:

- The ability to define a procedure as an interrupt handler as well as facilities for generating interrupts
- Direct support of byte, half-word, and word input and output from microprocessor ports
- Upward compatibility with Intel PL/M-286 and PL/M-86 source code

PL/M-386 combines the benefits of a high-level language with the ability to access the Intel386 architecture. For the development of systems software, PL/M-386 is a cost-effective alternative to assembly language programming.

FORTRAN-386 COMPILER

Intel's FORTRAN-386 compiler is a cross-compiler that supports the entire Intel 376 embedded processor.

FORTRAN-386 features high-level support for floating-point calculations, transcendentals, interrupt procedures, and run-time exception handling. Specifically, the FORTRAN-386 language is a superset of the language described in the ANSI Fortran 77 standard. The additions to that standard include the Department of Defense (DOD) extensions, extensions that support programs written for the ANSI Fortran 66 standard, and extensions that support the 376 processor and 80387SX math coprocessors.

To aid in the development and debugging process, the compiler generates warning and error messages and an optional listing file. The listing file can include symbol cross-reference tables and a listing of the generated 386 microprocessor assembly-language instructions. Library routines are reentrant and ROMable.

Other Intel FORTRAN-386 compiler features include:

- Object code can be configured to reside in either RAM or ROM
- The program code can be optimized for execution speed or memory size
- Source-level debugging is supported via the rich symbolics provided in the object module format (Intel OMF386)
- Support for the proposed REALMATH IEEE floating point standard

RLL-386 RELOCATION, LINKAGE, AND LIBRARY TOOLS

The RLL-386 relocation, linkage, and library tools are a cohesive set of utilities featuring comprehensive support of the full Intel 376 architecture. RLL-386 provides for a variety of

functions—from linking separate modules, building an object library, or linking in 387 SX support, to building a task to execute under protected mode or the multi-tasking, memory protected system software itself. Specifically, RLL-386 supports loadable, linkable, and bootloadable Intel object module formats; and supports all segmentation models, including FLAT. Map, librarian, and conversion (for outputting hex format code for PROM programming) utilities are included.

EMUL-387, NUM-387 NUMERICS SUPPORT LIBRARIES

Intel's EMUL-387 and NUM-387 Numerics Libraries fully support the 80387SX math coprocessor whether an actual math coprocessor is used in the final system or not.

For 376 microprocessor based applications without a math coprocessor, EMUL-387, a numerics software emulator, will execute instructions as though the coprocessor were present. Its functionality is identical to that of the math coprocessor. It is ideal for prototyping and debugging floating-point application software independent of hardware. Further, this permits portability of application code regardless of the presence of math coprocessor hardware in target systems.

For applications with a math coprocessor, NUM-387 numerics support library provides Intel's ASM 386, C-386, PL/M-386, and FORTRAN-386 language users with enhanced numeric data processing capability. With the library, it is easy for programs to do floating point arithmetic. Programmers can bind in library modules to do trigonometric, logarithmic and other numeric functions, and the user is guaranteed accurate, reliable results for all appropriate inputs.

Intel's NUM-387 support library is a collection of four functionally distinct libraries:

- Common elementary function library routines perform algebraic, logarithmic, exponential, trigonometric, and hyperbolic operations on real and complex numbers, as well as real-to-integer conversions; the routines extend the ranges of the coprocessor instructions
- Initialization library routines set up the numerics processing environment for 80376 microprocessor based systems with an 80387SX or true software emulator
- Decimal conversion library routines convert floating-point numbers from 80387SX binary storage format to ASCII decimal strings to 80387SX binary and vice versa
- Exception handling library routines make writing numerics exception handlers easier

All support library modules are in 80386 microprocessor object module format (Intel OMF386) so they can be linked with the object output of any Intel 80386 language. All routines are reentrant and ROMable.

By using Intel's NUM-387, the user not only saves software development time, but is guaranteed that the numeric software meets industry standard (ANSI/IEEE standard for binary floating point arithmetic, 754-1985) and is portable—software investment is maintained.

INTEL 376™ FAMILY DEVELOPMENT SUPPORT

INTEL 376™ IN-CIRCUIT EMULATORS

Intel 376 In-circuit Emulators embody exclusive technology that gives access to internal processor states that are accessible in no other way. Intel 376 processor fetch and execute instructions in parallel, with fetched instructions not necessarily executing in order of input. Because of this, an emulator without this access to internal processor states is prone to error in determining what actually occurred inside the microprocessor. With Intel's exclusive technology, Intel 376 emulator is one hundred percent accurate. In addition, internal access comes without signal buffer interference of processor timing. Operation is non-intrusive (zero wait-state).

Opening the Door to Protected Mode

The Intel 376 In-circuit Emulator opens the door to the full potential of the architecture with unparalleled support of protected mode. The emulator can display and modify task state segments and global, local, and interrupt descriptor tables (with symbolic access to all descriptor components like privilege level and segment type). Emulation memory of 128 Kbytes or the optional 2 Mbytes of relocatable expansion memory can be used instead of target memory for code debugging.

With symbolic debugging, memory locations can be examined or modified using symbolic references to the original program, such as procedure or a variable names, line numbers, or program labels. Source code associated with a given line number can be displayed, as can the type information of variables, such as byte, word, record, or array. Processor data structures, such as registers, descriptor tables, and page tables, can also be examined and modified using symbolic names. The symbolic debugging information for use with Intel development tools is produced by Intel OMF386 compatible languages.

Flexible and Versatile Event Recognition

Flexibility and versatility in event recognition makes short work of uncovering the most complex bugs. Bus even recognition circuitry may be used to trigger on specific or masked data input, output, read, written, or fetched at a physical address or range of addresses. Or on-chip debug registers may be used to trigger on virtual, linear, or symbolic addresses being executed, accessed, or written.

Versatility shows in other triggering options—upon a task switch, an external signal from another emulator or a logic analyzer, multiple occurrences of an event, a full trace buffer, halt or shutdown cycles, or interrupt acknowledge. And up to four sequential event triggers can be combined with a high-level construct.

The Intel 376 In-circuit Emulator continuously captures all bus activity and, as an option, execution information, into a trace buffer of 4K frames with PRE, POST, and CENTERED collection modes. The contents of the trace buffer can be displayed during full speed emulation in either execution cycle or machine-level instruction formats.

Accessing the Power

The power of the Intel 376 In-circuit Emulator is reflected in the sophisticated user interface. Refined for ease-of-use, the command line interface contains many features to boost productivity and customize functionality.

On-line help, a syntax menu, command line editing, command history, and error message query promote ease of learning and use. I/O redirection and the ability to escape the host operating system provide versatility for the power user. Customized procedures with variables and literal definitions can be created to assist in debugging or for manufacturing test or field service applications.

SOFTWARE DEBUGGER

Intel's DB386 is a useful tool for early software algorithm debug. It is an on-host software execution environment with source-level symbolic debug capabilities for object modules produced by Intel's assembler and high-level language compilers. For the DOS hosted version, this software debug environment allows 386 microprocessor code to be executed and debugged directly on a 386 DX or 386 SX™ microprocessor based PC, without any additional target hardware required. With Intel's standard windowed human interface, users can focus their efforts on finding bugs rather than spending time learning and manipulating the debug environment.

INTEL 376™ FAMILY DEVELOPMENT SUPPORT

Other Intel DB386 features include:

- A run-time interface allows protected-mode 376 microprocessor programs to be executed directly on a 386 DX or 386 SX microprocessor based PC
- Drop-down menus make the tool easy to learn for new or casual users. A command line interface is also provided for more complex problems
- Watch windows (which display user-specified variables), trace points, and breakpoints (including fixed, temporary, and conditional) can be set and modified as needed, even during a debug session
- The user can browse source and callstacks, observe processor registers, and access watch window variables by either the pull down menu or by a single keystroke using the function keys
- An easy-to-use disassembler and single-line assembler speeds the debug process
- The user need not know whether a variable is an unsigned integer, a real, or a structure—the debugger uses the wealth of typing information available in Intel languages to display program variables in their respective type formats

ICE™-376 SPECIFICATIONS AND REQUIREMENTS

HOST SYSTEM REQUIREMENTS

The user supplied host system can be either an IBM® PC AT® or Personal System/2® Model 60. Host system requirements to run the emulator include the following:

- DOS version 4.0, or Hewlett-Packard HP9000 UNIX
- 640 Kbytes of RAM in conventional memory
- An Above™ board with 1 megabyte of RAM configured in expanded memory mode, EMM.SYS software version 3.2
- A 20 MB hard disk
- A serial port or the National Instruments GPIB-PCII™, GPIB-PCIIA™, or MC-GPIB™ board
- A math coprocessor if either the optional time tag board is used or if a math coprocessor resides on the target system

ELECTRICAL CHARACTERISTICS

100-120V or 220-240V selectable
50-60 Hz
2 amps (AC max) @ 120V
1 amp (AC max) @ 240V

ENVIRONMENTAL CHARACTERISTICS

Operating Temperature: +10°C to +40°C (50°F to 104°F)

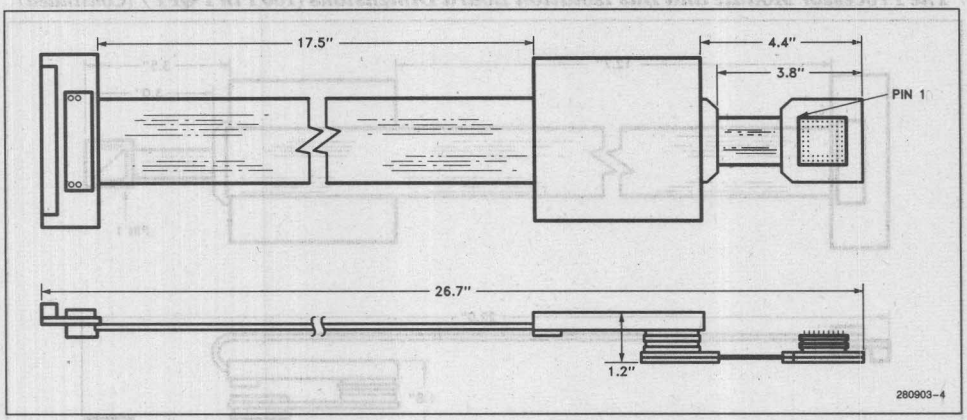
Operating Humidity: Maximum of 85% relative humidity, non-condensing

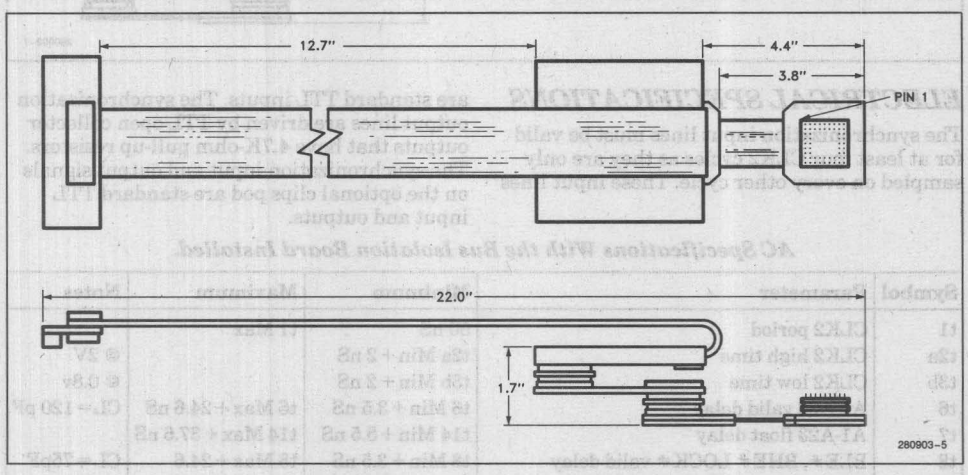
The Emulator's Physical Characteristics

Unit	Width		Height		Length	
	inches	cm	inches	cm	inches	cm
Base Unit	13.4	34.0	4.6	11.7	11.0	27.9
Processor Module	3.8	9.7	0.7	1.8	4.4	11.2
Optional Isolation Board	3.8	9.7	0.5	1.3	4.4	11.2
Power Supply	7.7	19.6	4.1	10.4	11.0	27.9
User Cable	1.9	4.8			17.3	43.9
100-Pin Target-Adapter Cable	2.3	5.3	0.5	1.3	5.1	13.0
88-Pin Target-Adapter Cable	2.3	5.3	0.5	1.3	5.8	14.7
Serial Cable					144	366
Optional Clips Pod	3.3	8.4	0.8	2.0	6.0	15.2

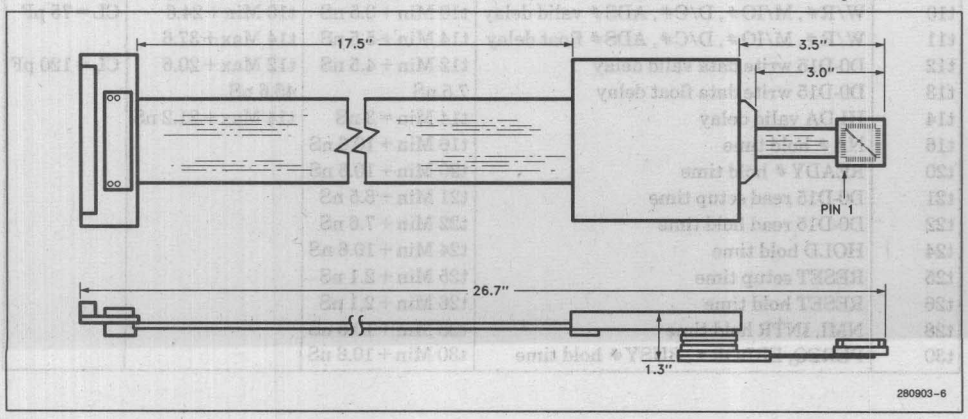
ICE™-376 SPECIFICATIONS AND REQUIREMENTS

The Processor Module and Bus Isolation Board Dimensions (88 Pin PGA)



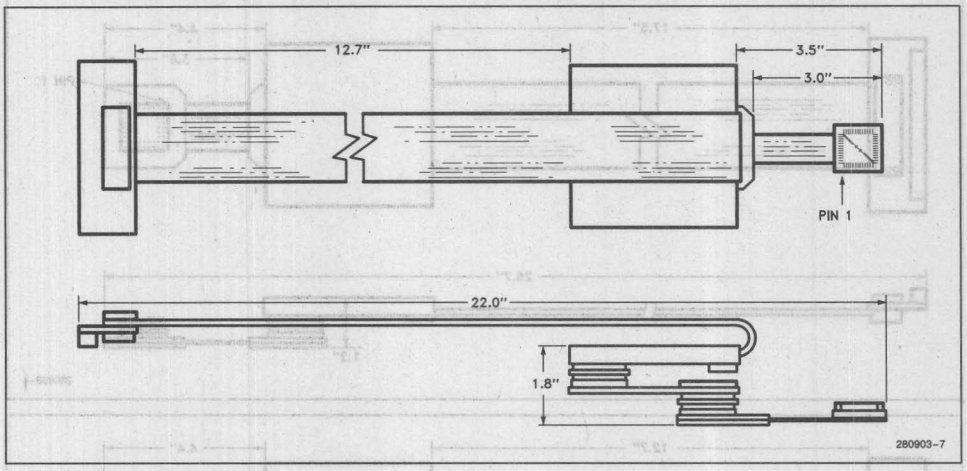


The Processor Module and Bus Isolation Board Dimensions (100 Pin PQFP)



ICE™-376 SPECIFICATIONS AND REQUIREMENTS

The Processor Module and Bus Isolation Board Dimensions (100 Pin PQFP) *(Continued)*



ELECTRICAL SPECIFICATIONS

The synchronization input lines must be valid for at least four CLK2 cycles as they are only sampled on every other cycle. These input lines are standard TTL inputs. The synchronization output lines are driven by TTL open collector outputs that have 4.7K-ohm pull-up resistors. The synchronization input and output signals on the optional clips pod are standard TTL input and outputs.

AC Specifications With the Bus Isolation Board Installed.

Symbol	Parameter	Minimum	Maximum	Notes
t1	CLK2 period	50 nS	t1 Max	
t2a	CLK2 high time	t2a Min + 2 nS		@ 2V
t3b	CLK2 low time	t3b Min + 2 nS		@ 0.8v
t6	A1-A23 valid delay	t6 Min + 3.5 nS	t6 Max + 24.6 nS	CL = 120 pF
t7	A1-A23 float delay	t14 Min + 5.5 nS	t14 Max + 37.6 nS	
t8	BLE#, BHE# LOCK# valid delay	t8 Min + 3.5 nS	t8 Max + 24.6	CL = 75pF
t9	BLE#, BHE# LOCK# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t10	W/R#, M/IO#, D/C#, ADS# valid delay	t10 Min + 3.5 nS	t10 Min + 24.6	CL = 75 pF
t11	W/R#, M/IO#, D/C#, ADS# float delay	t14 Min + 5.5 nS	t14 Max + 37.6	
t12	D0-D15 write data valid delay	t12 Min + 4.5 nS	t12 Max + 20.6	CL = 120 pF
t13	D0-D15 write data float delay	7.5 nS	45.6 nS	
t14	HLDA valid delay	t14 Min = 3 nS	t14 Max + 21.2 nS	
t16	NA# hold time	t16 Min + 10.6 nS		
t20	READY# hold time	t20 Min + 10.6 nS		
t21	D0-D15 read setup time	t21 Min + 8.5 nS		
t22	D0-D15 read hold time	t22 Min + 7.6 nS		
t24	HOLD hold time	t24 Min + 10.6 nS		
t25	RESET setup time	t25 Min + 2.1 nS		
t26	RESET hold time	t26 Min + 2.1 nS		
t28	NMI, INTR hold time	t28 Min + 10.6 nS		
t30	PEREQ, ERROR#, BUSY# hold time	t30 Min + 10.6 nS		

SPECIFICATIONS

Emulator Capacitance Specifications With Target-Adapter Cable Installed

Symbol	Description	Typical (Note 1)
C_{IN}	Input Capacitance	
	CLK2	55pf
	READY#, ERROR#	35pf
	HOLD, BUSY#, PEREQ, NA#, INTR, NMI	20pf
	RESET	30pf
C_{OUT}	Output or I/O Capacitance	
	D15-D0	50pf
	A15-A1, BLE#	40pf
	A23-A16, BHE#, D/C#	30pf
	HLDA, W/R#	55pf
	ADS#, M/IO#, LOCK#	35pf

Note 1: Not tested. These specifications include the 80376 component and all additional emulator loading.

Emulator DC Specifications Without the Bus Isolation Board Installed

Item	Description	Max.	Notes
PM-I_{CC}	Processor Module Supply Current	376-I_{CC} + 940 mA	
I_{IH}	Input High Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, HLDA	0.02 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.03 mA	1
	CLK2	0.04 mA	1
	RESET	0.06 mA	2
I_{IL}	Input Low Leakage Current		
	A23-A1, BLE#, BHE#, D/C#	0.6 mA	1
	D15-D0	0.06 mA	1
	ADS#, M/IO#, LOCK#, READY#, ERROR#	0.01 mA	1
	W/R#	0.51 mA	1
	CLK2	0.62 mA	1
	RESET	0.6 mA	2
	HLDA	0.02 mA	1

Note 1: This specification is the DC input loading of the emulator circuitry only and does not include any 80376 leakage current.
Note 2: This specification replaces the 80376 specification for this signal.

SPECIFICATIONS

Emulator DC Specifications With the Bus Isolation Board Installed

Item	Description	Min.	Max.
BIB-I_{CC}	Bus Isolation Board Supply Current		PM-I_{CC} + 350 mA
V_{OL}	Output Low Voltage (I_{OL} = 48 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#		0.5 v
	D15-D0, M/IO#, LOCK#, W/R#		0.5 v
	HLDA (I_{OL} = 24 mA)		0.44. v
	Output High Voltage (I_{OH} = 3 mA)		
	A23-A1, BLE#, BHE#, D/C#, ADS#	2.4 v	
	D15-D0, M/IO#, LOCK#, W/R#	2.4 v	
	HLDA (I_{OH} = 24 mA)	3.8 v	
I_{IH}	Input High Current		
	CLK2, RESET		1.0 μA
	READY#		25 μA
I_{IL}	Input Low Current		
	CLK2, RESET		1.0 μA
	READY#		250 μA
I_{IO}	Output Leakage Current		
	A23-A1, BLE#, BHE#, D/C#, ADS#		±20 μA
	D15-D0, M/IO#, LOCK#, W/R#		±20 μA

PROCESSOR MODULE INTERFACE CONSIDERATIONS

With the processor module directly attached to the target system without using the bus isolation board, the target system must meet the following requirements.

- The user bus controller must only drive the data bus during a valid read cycle of the emulator processor or while the emulator processor is in a hold state (the emulator processor uses the data bus to communicate with the emulator hardware).
- Before driving the address bus, the user system must gain control by asserting HOLD and receiving HLDA.
- The user reset signal is disabled during the interrogation mode. It is enabled in emulation, but is delayed by 2 or 4 CLK2 cycles.
- The user system must be able to drive one additional TTL load on all signals that go to the emulation processor.

When the target system does not satisfy the first two restrictions, the bus isolation board is used to isolate the emulation processor from the target system. With the isolation board installed, the processor CLK2 is restricted to running at 20 MHz.

The processor module derives its DC power from the target system through the 80376 socket. It requires 1400mA, including the 80376 current. The isolation board requires an additional 350mA.

The processor must be socketed, for example using Textool 2-0100-07243-000 or AMP 821949-4 sockets.

The printed circuit board design should locate the processor socket at the physical ends of the printed circuit board traces that connect the processor to the other logic of the target system. This reduces transmission line noise. Additionally, if the target system is enclosed in a box, pin one of the processor socket should be oriented away from the target system's box opening to make connecting the target-adapter cable easier.

ORDERING INFORMATION

SERVICE, SUPPORT, AND TRAINING

To augment its development tools, Intel offers a full array of seminars, classes, and workshops, field application engineering expertise, hotline technical support, and on-site service.

Intel also offers a Gold Software Support package which includes:

Technical software information phone support,
Automatic distribution of software and documentation updates
Access to the "ToolTalk" electronic bulletin board

Intel's Hardware Support package includes:

Technical hardware information phone support,
Warrantee on parts/labor/material
On-site hardware support
One Customer Training Course of choise, plus discounts on additional customer training and SE consulting

SOFTWARE DEVELOPMENT TOOL

Order Code	Description
D86ASM386NL	DOS Macro Assembler supports 80386/80376
D86C386NL	DOS C Compiler supports 80386/80376
D86PLM386NL	DOS PL/M Compiler supports 80386/80376
D86FOR386NL	DOS FORTRAN Compiler supports 80386/80376
D86RLL386NL	DOS S/W DEV Package Builder/Binder/Mapper/ Librarian. Supports 80386/ 80376
DASM386PLUS	DOS ASM Developers Kit, Inc. ASM, NUM, RLL and EMUL
DB386	DOS S/W Debugger for 80386
D86NUM387NL	DOS 80387 Numerics Libraries
EMUL387SU	387 Numerics Coprocessor S/W Emulator object code
EMUL387RO	EMUL-387 to form derivative works. Requires incorporation fee
	Requires prior purchase of EMUL-387RF
EMUL387RF	EMUL-387 one time incorp fee

IN-CIRCUIT EMULATOR

pICE376D	ICE376 In-circuit Emulator for 80376 component. Operates to 16 MHz. Includes control unit, power supply, 376 Processor Module with PQFP adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
ICE37620D	ICE376 In-circuit Emulator for 80376 component. Operates to 20 MHz. Includes control unit, power supply, 376 Processor Module with PQFP adaptor, Stand-Alone Self-Test board, bus Isolation Board, and DOS 3.x host software and interface cable.
REM386SX376	2 Mbytes relocatable expansion memory
pICE386TO376D	Conversion kit to adapt ICE386 25 MHz emulator to support the 80376 component. Operates to 16 MHz. Includes ICE376 emulator Processor Module and DOS 3.x host software.
pICE386SXTO376D	Conversion kit to adapt ICE386SX 16 or 20 MHz emulator to support the 80376 component. Operates to 16 MHz. Includes ICE376 emulator Processor Module and DOS 3.x host software.

ORDERING INFORMATION

p88PGAADAPT	Adaptor for ICE376 emulator to support 88 pin PGA component packaging.
pICE3XXCPO	Clips Pod Option for ICE376, ICE386SX 16 or 20 MHz, ICE386 25 MHz, and ICE386DX 33 MHz emulators.
pICE3XXTTB	Time Tag Board Option for ICE376, ICE386SX 16 or 20 MHz, ICE386 25 MHz, and ICE386DX 33 MHz emulators.
DT0AB	2 MB Intel Above Board.